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ANTI-EXPOSURE TECHNOLOGY IDENTIFICATION FOR MISSION SPECIFIC OPERATIONAL REQUIREMENTS

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A selected group of anti-exposure garment configurations have been evaluated at the Naval Air Development Center to determine their comparative levels of performance in the areas of mobility/reach, heat stress/comfort, and immersion hypothermia protection. The specific results of these evaluations are reported, as well as a discussion of how the results relate to the U.S. Navy Operational Requirements for cold water exposure protection, as currently specified by the CNO. Recommendations concerning the optimum technological

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INTRODUCTION

The global nature of Navy operations results in the exposure of aircrewmen to the full range of climatic extremes. Aircraft deployments over cold water regions, with the continued likelihood of emergency ditchings or bailout into water below 15.6° C (60° F), requires special protection for aircrews and accompanying personnel if they are to survive long enough for Search and Rescue (SAR) efforts to be successful. The special protection required for personnel accidentally immersed in cold water (for our purposes defined as below 16° C) must prevent two potentially lethal consequences: drowning and hypothermia. A reliable personal flotation device (PFD) can readily prevent drowning, but the provision of hypothermia protection is a much more complex problem for military personnel. Since emergency egress into cold water often occurs with little or no warning, the need exists for protective devices to be worn throughout all flight missions conducted over cold water regions. Since successful mission accomplishment is the primary consideration, protective devices must be designed to minimally degrade the performance of the wearer. A number of factors, including mobility, thermal comfort, fire protection, reliability, maintainability, and logistic supportability must be considered when selecting a configuration suitable for constant wear in flight. Further consideration of these factors must be balanced with the ability of an individual configuration to prevent immersion hypothermia when selecting the optimum equipment.

In this study, 21 configurations of various types and origins were selected for evaluation. The configurations were evaluated for comparative levels of immersion hypothermia protection as well as for their effects on mobility and reach, heat stress, fire protection, reliability, maintainability, and logistics.

BACKGROUND

Currently the U.S. Navy is utilizing, to varying degrees, a variety of anti-exposure garments. Fleetwide dissatisfaction has resulted because these garments do not meet all of the mission specific operational and logistics requirements of the Fleet. Traditionally, the selection of anti-exposure equipment has been based primarily on the ability of the equipment to provide immersion hypothermia protection for 2 hours in 0° C water. Little consideration has been given to the negative effects, caused by the limitations and restrictions of such equipment, on in-flight performance.

In February 1979, the Chief of Naval Operations (CNO) established an operational requirement (OR W1159-SL) for Cold Water Exposure Protection which details requirements in terms of immersion hypothermia prevention as well as in-flight performance. The OR establishes a requirement for an anti-exposure system which is capable of protecting personnel in water temperatures down to 7° C, for a period of 2 hours immersed time, without them suffering any permanent physiological damage or impairment. This level of protection is to be provided without the use of a flotation platform. The requirement for a second stage system capable of protecting personnel exposed to water temperatures of 0 to 7° C, for a period of 2 hours, has been established. This second stage system can utilize a flotation platform, provided its availability is guaranteed to each individual. Physiological limitations are set at a minimum body core temperature of 35° C, a minimum hand temperature of 10° C for the first stage system and 16° C for the second stage system, and a minimum foot skin temperature of 0° C.

In addition to the exposure protection requirements, the OR also requires that the system: (1) not support combustion; (2) be compatible with existing and proposed flight and survival equipment, crew stations, and overall mission accomplishment; (3) impose minimum physical restrictions on aircrew; and (4) restrict body core temperature from heat build-up during flight to below 38.5°C. Reliability, maintainability, and logistic supportability are also to be given consideration.

The investigations reported herein were conducted to identify the current anti-exposure technologies which most closely meet the requirements of this OR as it relates to the specific missions of ejection seat, fixed seat, and mobile crewmen. It is an attempt to identify the best compromises with respect to survival performance, mobility, heat stress, fire protection, reliability, maintainability and logistics.

MISSION SPECIFIC REQUIREMENTS ANALYSIS

Naval aircrewmen can be categorized by the aircraft type to which they are assigned, by the type of seat they utilize during flight, and by their individual duties throughout the flight mission.

There are three basic aircraft types: (1) Fighter/Attack Jet Aircraft, (2) Rotary Wing Aircraft (Helicopters) and (3) Fixed Wing Non-jet aircraft. All Fighter/Attack Aircraft are equipped with ejection seats. The Rotary Wing and Fixed Wing aircraft have some fixed seats to which specific crewmembers are assigned and are seated in throughout the flight mission. Some Rotary Wing and Fixed Wing aircraft also have additional seating for crewmembers, troops and/or passengers who have no fixed seat assignments. Where exceptions exist, such as in jet powered patrol aircraft, categorization is based on the specifics of the aircrew seating, i.e., fixed seat or ejection seat.

Flight mission duties fall into two general categories — those performed by crewman who remain seated throughout flight and those performed by crewmen who are mobile during some phase of the flight mission. Those who remain seated are generally tasked with duties which involve intellective and psychomotor skills rather than distinct physical work. Mobile crewmen are generally tasked with duties which require some degree of physical exertion during certain phases of the flight mission, usually performed at an assigned duty station within the aircraft.

For purposes of this evaluation, and in accordance with the Navy Operational Requirement, the specific requirements of crewmen are being considered in three general groups: (1) Fighter/Attack ejection seat crewmen; (2) Fixed Wing and Rotary Wing crewmen assigned to fixed seats and (3) mobile crewmen on Fixed Wing and Rotary Wing Aircraft.

Table I provides an overview of the Fighter/Attack Aircraft missions and crewmen. Although each aircraft has its own specific missions and crew, certain key factors should be considered in the design of personal equipment for all of these crewmen. First, most crew spaces in the Fighter/Attack aircraft are extremely limited in size. In addition, the duties of these crewmen are highly demanding mentally due to the critical missions they perform in combat and the high performance nature of the aircraft and its resultant g-loads. These factors make excessive bulk, warmth, or mobility restriction of crew-mounted gear unacceptable. In terms of specific mobility and reach requirements, figure 1 illustrates some critical requirements of the various Fighter/Attack aircraft. In general, upper body mobility is critical for these crewmen rather than full-body mobility. It should be noted that for the critical movement of forward reach, two of the aircraft types (A-7 and A-6) have requirements which are beyond the capability of a certain segment of the aircrew population even without the added encumbrance of an anti-exposure configuration. Air conditioning of the Fighter/Attack aircraft is provided, so ambient temperatures within the aircraft are generally not excessive. Mission duration normally averages from 2 to 3 hours but can be extended to as much as 6 or 7 hours with refueling of the aircraft.

Table I. Fighter/Attack Mission Analysis

Aircraft Series	Missions	Mission Length	Crawmember and Responsibilities	Comments
A-6	All-Weather Day/Nite Attack Nuclear Weapon Delivery Mina Laying Electronic Warfara Ops. Electronic Reconnaissance/ Intelligenca	3-3½ hrs. Averaga 5 hrs. Maximum	Pilot: Responsibla for flying aircraft Bombadier/Navigator: Determines optimum approach to and from target area & most accurate delivary of weapons/ordnanca carriad by aircraft	Forward reach raquiremant is beyond the capability of soma aircrewmen
A-7	Light Attack Closa Air Interdiction Advanced Trainer - (Prototypa Aircraft) Inflight Tankar Refueling (Special Conversions only)	1½-2½ hrs.	Pilot: Flys aircraft and delivers weapons/ ordnanca on designated targets	Small cockpit size is restrictive to movement of larga aviator Forward reach . . . (as above)
S-3	ASW Saarch & Surveillance from Sea-Based (CV) Platforms	4 hrs. +	Pilot: Flys aircraft Co-Pilot: Alternate to pilot; operatas & monitors non-acoustic sensors (such as infrared & radar); navigates aircraft Tactical Coordinator (TACO): Formulates strategy and guides pilot for nacassary maneuvars and tactics against sub Sensor Operator (SENSO): Oparates and monitors acoustic sensors i.a. sonobuoys	
AV-8 (Harrier) Vertical Short Take-off & Landing (V/STOL) Strike Fighter	Attack Mission for Close Air Support OPS (CAS) Tactical Reconnaissance (when equipped) Training OPS	2½-3 hrs. Average 7 hrs. Maximum	Pilot: Flys aircraft and delivers weapons/ ordnanca on designated targets	V/STOL characteristics make tha tasks of pilot more difficult than usual; highly fatiguing & demanding
A-5	Reconnaissance Attack Bombing	2.5-3 hrs. Average 6 hrs. Maximum	Pilot: Flys and commands aircraft Naval Flight Officer (NFO) Sensor Station Operator: Control and operation of reconnaissance sensors	
A-4	Carrier Based Light Attack Light Tankar Refueling Light Attack Bomber Trainer High Performance Attack	2.5-3 hrs.	Pilot: Flys and delivers weapons/ordnance on designated targets NOTE: TA-4F/J trainers ara tandem seat	Tiny cramped cockpit
F-14	Fighter/Sweep Escort Strike Forca Defense via Combat Air Patrol (CPA) and Deck Launched Intercept (DLI) OPS Secondary Attack of Tactical Ground Targets	2 hrs. Average 3¾ hrs. Maximum	Pilot: Flys aircraft Radar Intercept Officer (RIO): Navigation, sensor operation & monitoring, fire control of weapons system	Inherent high performanca subjacts man to high "G" loads (+12G) in diff. vectors
F-4	All Weather Attack Fightar Reconnaissance/Intelligenca High Speed Interceptor/ Attack	1½-2 hrs. Average 3-3½ hrs. Maximum	Pilot: Flys aircraft Radar Intercept Officer (RIO) "OR" Naval Flight Officer (NFO): Control and employment of electronic systems including navigation. Sensors & fire control	High performanca aircraft creates "G" load vectors (+8G) on personnal especially during air combat maneuvers (ACM)

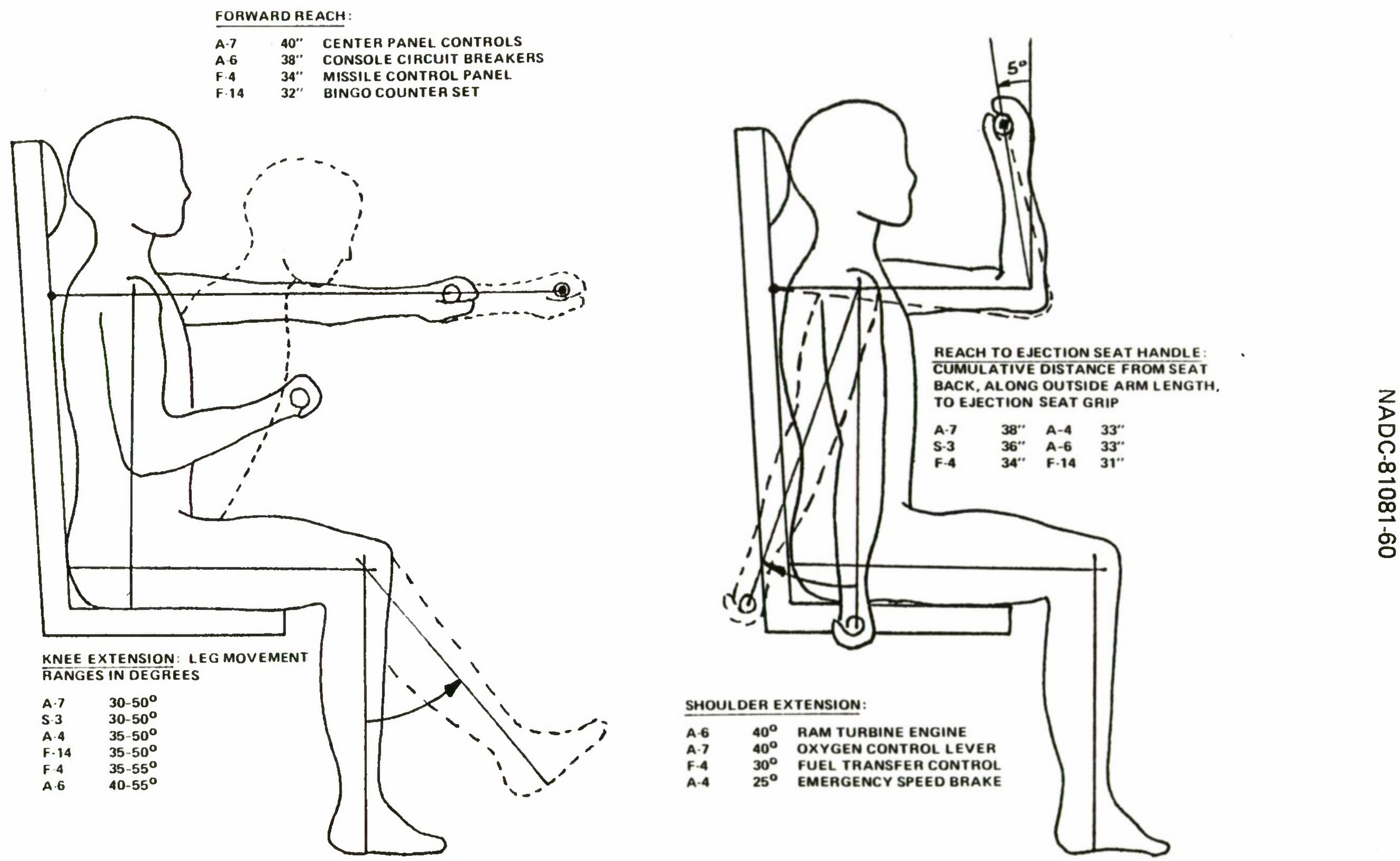

Figure 1. Critical Mobility and Reach Requirements of Fighter/Attack Aircraft

Table II provides an overview of the Rotary Wing and Fixed Wing aircraft missions and crewmen. Once again each aircraft has its own specific missions and crew, but certain generalities can be made about the two groups of crewmen; those in fixed seats and those who are mobile during some phase of the flight mission.

The crewmen assigned to fixed seats are generally tasked with duties which require mental, rather than physical, skills. The crew spaces within these aircraft are not so cramped as in the Fighter/Attack aircraft and high "g"-loads are not experienced. However, physical stress is experienced in the form of high ambient temperatures in helicopters which lack air-conditioning. These temperatures can reach as high as 115° F in the summer and 95° F in the winter.

These crewmen are also faced with emergency ditching or bailout procedures which require them to disconnect from their seats and egress from the aircraft through one of several windows or through the main personnel door. The one exception to this is for the AH-1 series of helicopters which carry only a pilot and co-pilot who exit through twin independent canopies. The normal mission length for both rotary wing and fixed wing aircraft is 3 to 4 hours, but this time can be extended to as much as 8 hours with refueling.

The mobile crewmen assigned to these aircraft are faced with the additional stress of having to perform highly physical activities at some time during the flight mission. These physical duties require such diverse tasks as lifting equipment, lowering cables, carrying cargo and equipment and assisting survivors during SAR operations. These duties are usually performed at assigned stations in various body positions including prone, kneeling, or standing. The most demanding duties are those of the Mine Counter Measures (MCM) crewmen who must lift and carry equipment weighing as much as 95 pounds, connect and lower this equipment into the water, and then repeat these actions in reverse for recovery operations. A high degree of full body mobility is required to perform these duties.

Figure 2 illustrates some of the critical mobility and reach requirements of fixed seat crewmen in rotary wing and fixed wing aircraft. The specific mobility requirements of mobile crewmen vary with the individual duties of each crewmen and mission, making it difficult to generalize. It must be stressed that the highest degree of full body mobility is required for these crewmen, and that their equipment should be selected to minimize body restriction as much as possible.

Table II. Rotary Wing and Fixed Wing Mission Analysis

Mission Type & Objective/Aircraft Type	Crewmember	Flight Duties	Seat Type	Normal Egress	Emergency Egress
Gunfire Support: Provide aerial gunfire suppression in support of ground operations and visual reconnaissance./ AH-1J, AH-1G	Pilot Co-Pilot (Gunner)	Fly helo after pre-flight Fly helo; delivering suppressive fire	Fixed Fixed Twin independent canopies	Through the canopy	Activate linear explosive system to cut windows from canopy
Vert. Rep. of Cargo: Rapid pickup, transport, & delivery of cargo, material and personnel/CH-46	Pilot Co-Pilot Vert. Rep. Crewmen (2-3) (As many as 8 crewmen)	Fly helo after pre-flight Fly helo after pre-flight Pre-flight – Inspect hook assy for proper functioning At destination – Assume prone position on deck at hatch openings to: 1) Guide pilot to correct location 2) Manually activate hook release for cargo drop	Fixed No fixed seat assignments – Assigned stations for vert. rep. duties (stand or prone)	Through main entrance door	Through main door or one of six windows
Search and Rescue: Rapid locating and rescue of downed aviator in combat environment; if not accompanied by VA or VF, must carry on suppressive fire./ SH-3G	Pilot Co-Pilot	– Preflight helo – Fly helo – Locate Survivor – Determine best rescue approach – Decide when to send down rescue crewman	Fixed seat	Through personnel door	Through personnel door or one of five windows
	Rescue Crewmen	– Lets out cable to survivor and hoists up – If survivor injured: – Lowers to survivor – Assist survivor's injuries and disentangle from equip. – Position survivor in retrieval device – Signal pilot for pickup and ride up w/survivor	No fixed seat assignment; mobile at rescue site		
Mine-Counter-Measures: Defeat moored, magnetic or acoustic mines/ RH-53, CH-53 (A/D)	Pilot Co-Pilot MCM Crewmen (5 min.)	Pre-flight helo Fly helo Misc. lifting, carrying, connection to cables & lowering of: 45 lb. floats, 95 lb. otters, and 8 lh. cutters (repeating actions in reverse for recovery OPS)	Fixed No fixed seat assignments; assigned Stations for MCM duties at mission site	Through personnel door	Through personnel door or one of nine windows or through rear compartment ramp if lowered.

Table II. Rotary Wing and Fixed Wing Mission Analysis (Continued)

Mission Type & Objective/Aircraft Type	Crewmember	Flight Duties	Seat Type	Normal Egress	Emergency Egress
Cargo and Troop Transport (Heavy Assault): Effect rapid delivery of men and material (cargo) to a combat zone/CH-53 (A/D) Methods of cargo delivery: 1) External: Same as vert. rep. of CH-46 2) Internal: Transport of motor vehicles and pallet loads which are packaged & secured to loading platforms Sometimes, external cargo and internal troop transport are combined.	Pilot Co-Pilot Crew Chief and other crewmembers	Pre-flight helo Fly helo Load and tie down cargo prior to flight; conduct vert. rep. ops. if reqd.; unload cargo at destination	Fixed seat No fixed seat assignment; set stations for performance of vert. rep. ops.	Through personnel door	Through personnel door or one of nine windows or through rear compartment ramp if lowered.
Anti-Submarine Warfare: Search, detection and identification of subs.; 2° – SAR or light cargo (e.g. mail) and passenger delivery/SH-3 (A, D&H)	Pilot Co-Pilot Sonar Operator Asst. Sonar Operator	Pre-flight helo Fly helo; dipping sonar ASW: Operate sonar display raise and lower sonar dome (not physical tasks) SAR: 1) Provide supplemental visual locating and directional info. to pilots 2) Steer helo to precise location point 3) Lower and raise rescue hoist cable	Fixed seat ASW: Fixed seats SAR & Light Cargo: No fixed seat assignments	Through personnel door	Through personnel door or one of four windows or through rear cabin door
Airborne Early Warning (AEW), Command Coordination (Sea/Air/Land) and Communications Coordination/E2	Pilot Co-Pilot Radar Operator Air Intercept Operator (AIO) Coordinator/Communicator	Flys aircraft Alternate to pilot; navigates Target search detection and tracking Works with radar oper. to communicate and vector interceptors against hostile air targets Coordiates radar, communication nets, and intercept activities of crew	Fixed seat	1. Manual disconnect of seat harness 2. Climb out of seat & over and around adjacent console 3. Exit through 21 inch corridor to fuselage door 4. Parachute out of hatch	Same as normal Note: Most demanding agress procedures of all aircraft types.

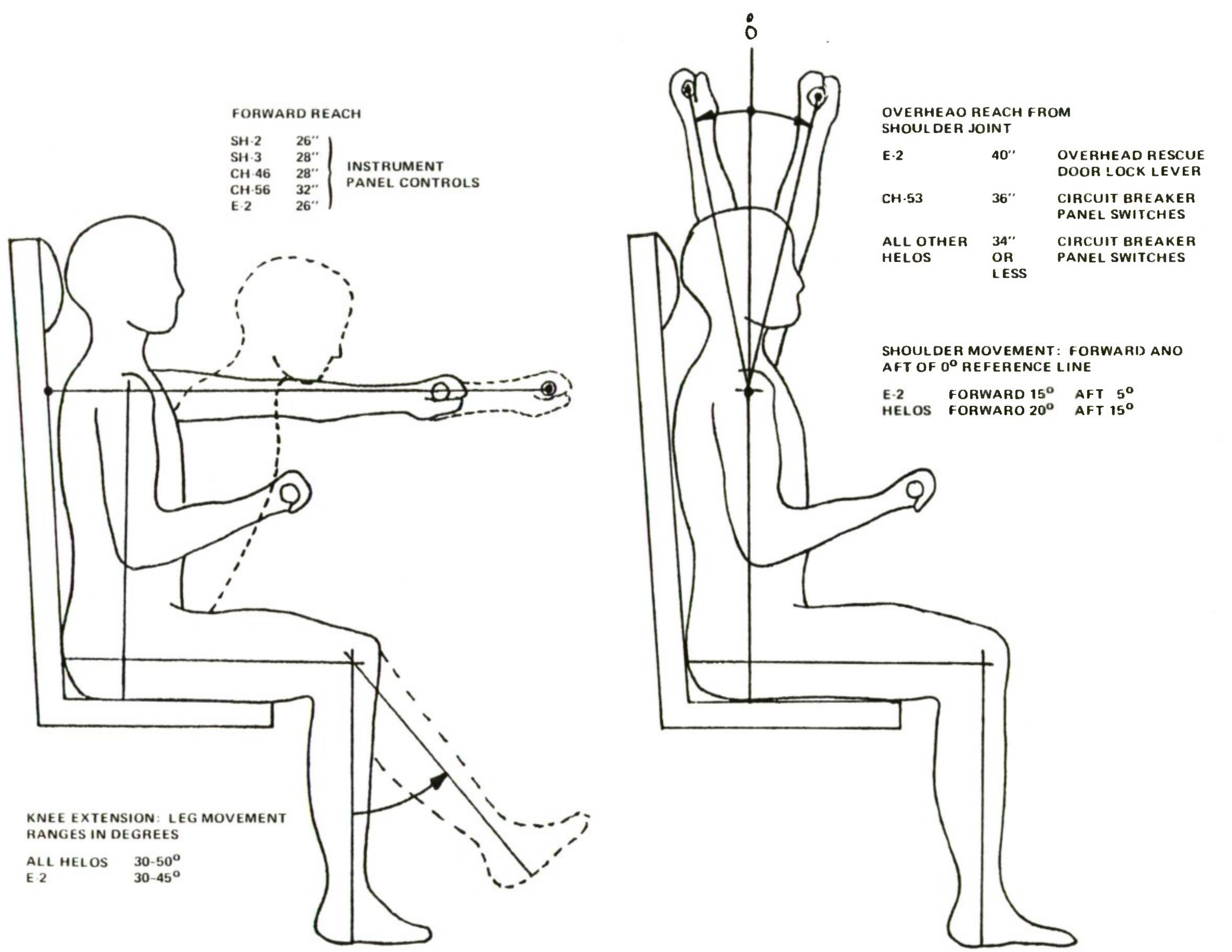

Figure 2. Critical Mobility and Reach Requirements of Fixed Seat Crewmen in Rotary Wing and Fixed Wing Aircraft

GARMENT CONFIGURATION SELECTION

The garment configurations selected for this evaluation represents four major design concepts available from domestic and foreign sources. Table III provides a description of the four major concept groups and a listing of the specific garments in each group. Garments are listed by code number, name, and country of origin. Figure 3 provides photographs of the garments which are individually described as follows.

DESCRIPTIONS

WF1 – Mustang UVic Thermofloat Jacket

This jacket is fabricated from two layers of polyurethane coated nylon fabric interspaced with closed cell ensolite foam. A fold out neck flap and convertible shorts fabricated of 1/8 inch thick neoprene foam can be deployed before or after water entry. These are normally stowed inside the jacket except in the survival mode when they give extra protection to the vital groin and upper body areas. The collar conceals a high visibility hood with reflective tape. Recessed knitted storm cuffs are provided at the wrists. It is available in four men's sizes and two women's sizes.

WF2 – Australian UVic Flight Jacket

This jacket is constructed of two layers of potassium flurozirconate (PFZ) treated wool interspaced with neoprene rubber (3.2 mm. thick). It has concealed noeprene foam flaps which can be pulled out to protect the high heat loss areas of the groin and throat. There is also a high visibility hood fabricated of polyurethane coated nylon stowed under the collar except in the survival mode. This jacket is standard issue for Australian P-3 flight crews. It is available in 12 sizes.

WF3 – Parkway Surfer Shorty Suit – Style MTS616

This wet suit is designed with short legs to mid-thigh and short sleeves to mid-bicep. It is fabricated of 1/8 inch thick neoprene foam with nylon bonded to the inside and a textured outside. It is collarless and has an offset front entry zipper and is available in six men's sizes and six women's sizes.

WF4 – Parkway One Piece Jumpsuit – Style MSO412

This full length wet suit has long sleeves and is fabricated of 1/8 inch gas blown neoprene foam with nylon bonded to both the inside and outside. It has a hook and pile fastened collar and a full length offset front entry zipper. It is available in six sizes.

WF5 – Parkway Two Piece Full Wet Suit – Style MSS116

This full length wet suit has long sleeves and is fabricated of 1/8 inch gas blown neoprene foam with nylon bonded to the inside and a textured outside. It has a beaver tail jacket and high waisted pants. Zippers are provided at the ankles, wrists, and center front. It is available in six men's sizes and six women's sizes.

Table III. Anti-Exposure Configurations Studied

DESIGN CONCEPT	SUIT CODE#	SUIT NAME	COUNTRY OF MANUFACTURE
WET FOAM (WF): ALLOW LIMITED WATER ENTRY; FABRICATED AT LEAST PARTIALLY OF CLOSED CELL INSULATING FOAM	WF1	MUSTANG UVIC THERMOFLOAT JACKET	CANADA
	WF2	UVIC FLIGHT JACKET	AUSTRALIA
	WF3	PARKWAY SURFER SHORTY SUIT (STYLE MTS616)	U.S.
	WF4	PARKWAY ONE-PIECE JUMPSUIT (STYLE MS0412)	U.S.
	WF5	PARKWAY TWO-PIECE FULL WET SUIT (STYLE MSS116)	U.S.
	WF6	CWU-33A/P ANTI-EXPOSURE FLYING COVERALL	U.S.
	WF7	MUSTANG SURVIVAL SUIT (MODEL 175)	CANADA
WET (W): ALLOW FREE WATER ENTRY WITH NO SPECIFIC THERMAL INSULATION LAYERS	W1	CWU-27/P SUMMER FLYING COVERALL	U.S.
	W2	CWU-48/P KNIT ARAMID FLYER'S COVERALL	U.S.
	W3	ILC VARI-TEMP TUBE SUIT	U.S.
DRY SUITS WITH INSULATION (DI): PREVENT WATER ENTRY AND HAVE SOME INHERENT THERMAL INSULATION	DI 1	IMPERIAL "BUBBLE" SUIT	U.S.
	DI 2	IMPERIAL SURVIVAL SUIT NO. 1409	U.S.
	DI 3	ILC AE2 ANTI-EXPOSURE COVERALL	U.S.
DRY WITHOUT INSULATION (D): PREVENT WATER ENTRY BUT HAVE NO INHERENT THERMAL INSULATION	D1	CWU-21/P ANTI-EXPOSURE ASSEMBLY	U.S.
	D2	MK-10 RAF IMMERSION AIRCREW COVERALL	ENGLAND
	D3	SWEDISH A.F. IMMERSION SUIT-STYLE NO. 82	SWEDEN
	D4	CANADIAN MK-1 CONSTANT WEAR IMMERSION SUIT	CANADA
	D5	NADC EXPERIMENTAL "GORETEX" COVERALL (PLAIN WEAVE)	U.S.
	D6	NADC EXPERIMENTAL "GORETEX" COVERALL (TWILL WEAVE)	U.S.
	D7	DANISH FLYER'S ANTI-EXPOSURE COVERALL	DENMARK
	D8	JAPANESE ANTI-EXPOSURE SUIT	JAPAN

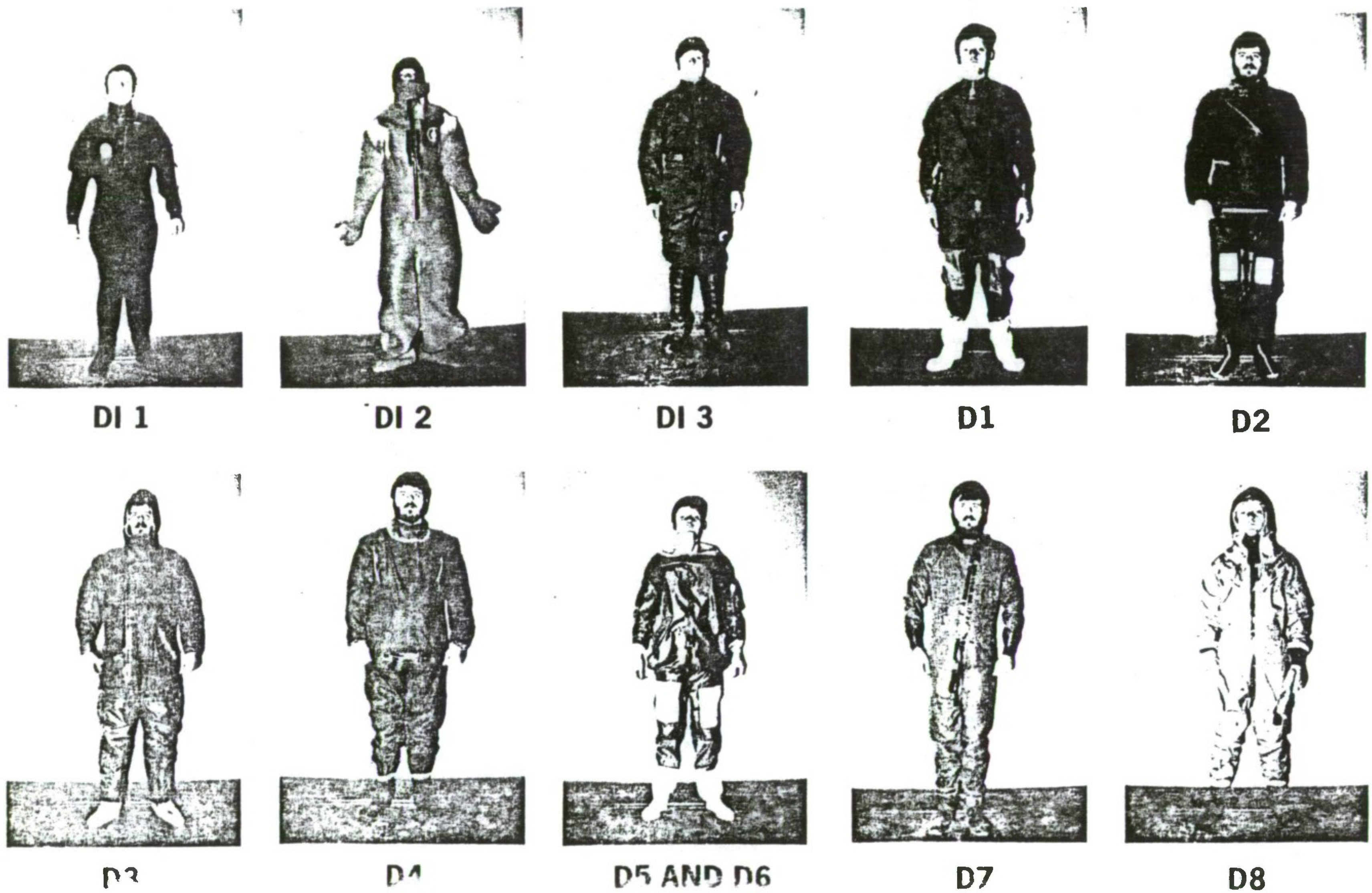

Figure 3. Photographs of Configurations Studied (Sheet 1 of 2)

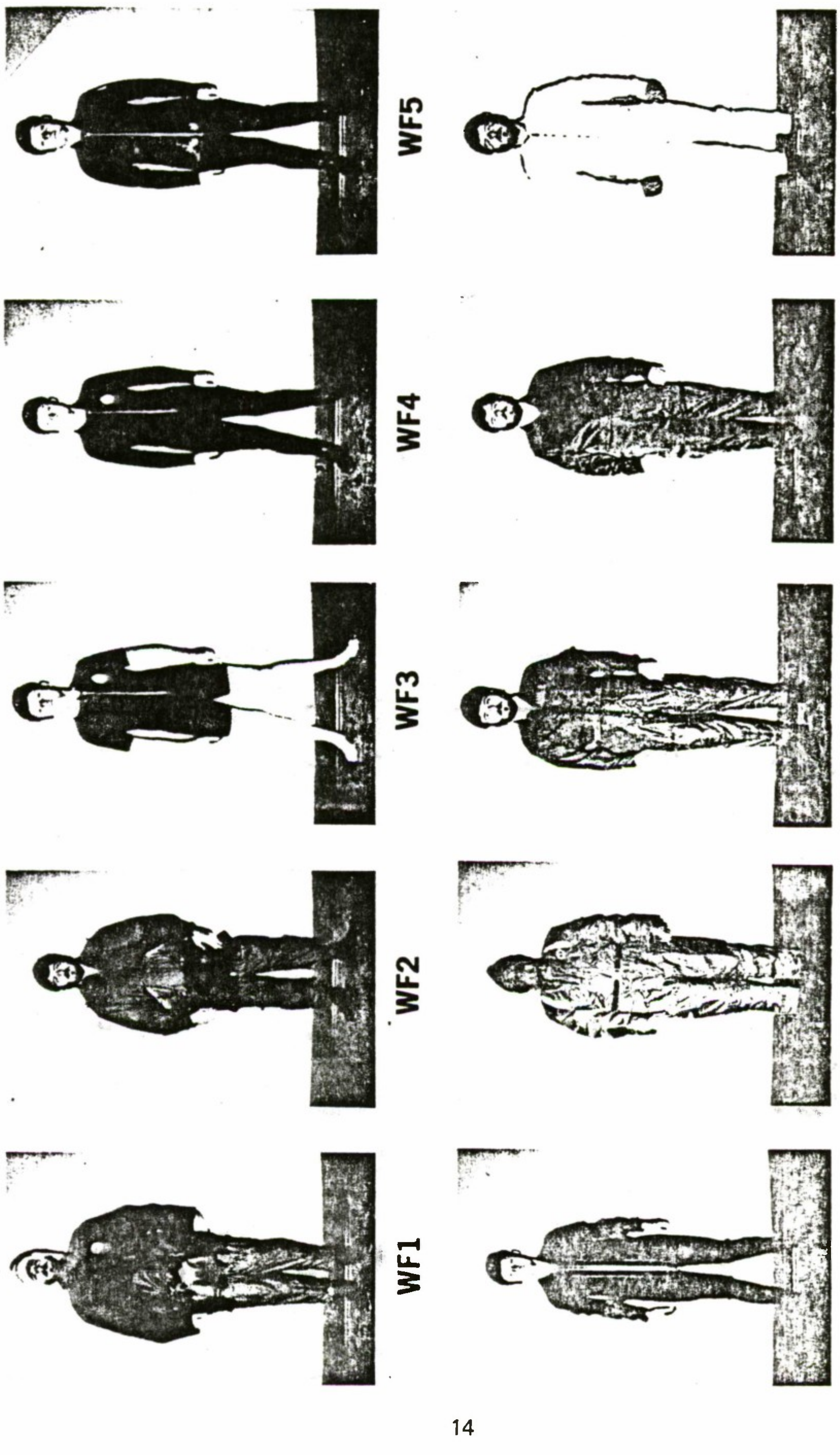

Figure 3. Photographs of Configurations Studied (Sheet 2 of 2)

WF6 – CWU-33A/P Anti-Exposure Flying Coverall

This wet suit is fabricated of 1/8 inch chemical blown neoprene foam with nylon lining skin and textured outer. It is a one-piece garment with full length legs to the ankle and sleeves to just above the elbow. Fabric sleeve extensions for protection of the lower arm are fabricated of high temperature resistant aramid ("Nomex"). It has a full length center front zipper and ankle zippers. It also incorporates a ventilation system constructed of polychloroprene coated nylon with a ventilation port on the left side chest. It is available in twenty sizes.

WF7 – Mustang Survival Suit – Model 175

This work coverall is fabricated of a nylon outershell lined with closed cell ensolite foam. The torso area has additional foam for greater protection. A detachable ensolite-lined hood and a hook and pile fastened storm flap are provided for extra thermal protection. Adjustable leg straps at the lower thighs are provided to minimize water seepage to the groin and trunk areas of the body. Wrist and leg closures have hook and pile tapes for tighter fitting to limit water entry. It is available in four sizes.

W1 – CWU-27/P Summer Flying Coverall

This coverall is a one-piece full body garment fabricated of 4.5 oz/yd^2 high temperature resistant aramid woven fabric. It is to be worn with two layers of high temperature resistant aramid thermal underwear for minimal cold water protection. It is available in twenty sizes.

W2 – CWU-48/P Knit Aramid Flyer's Coverall

This one-piece full body garment is constructed of 8.5 oz/yd^2 high temperature resistant aramid warp knit fabrics. It is to be worn with two layers of high temperature resistant aramid thermal underwear for minimal cold water protection. It is available in twenty sizes.

W3 – ILC Vari-Temp Tube Suit

This full body garment is constructed of nylon spandex fabric with an integral system of small diameter plastic tubing. It is designed for use with either a liquid cooling or liquid heating system. It is to be worn as the underwear layer of a light clothing system. It is available in three sizes.

DI1 – Imperial "Bubble" Suit – Style 923R

This full body garment is constructed of 1/4 inch neoprene foam with nylon laminated inside and outside. It is sealed at the neck, ankle, and wrists. It inflates either orally or with an auto inflator through a hose attachment at the chest. A waterproof slide fastener across the back shoulder area is used for suit entry. It is available in five sizes.

DI2 – Imperial Survival Suit No. 1409

This full body dry suit is designed for quick donning during an emergency. It is fabricated of 3/16 inch neoprene foam and is designed with integral boots, mitts, and hood leaving only the eyes and nose exposed. One size fits all up to 6 feet 4 inches tall and 300 pounds. It is donned through a center front waterproof zipper.

D13 – ILC AE2 Anti-Exposure Coverall

This full body garment uses a vapor permeable water barrier constructed of "Goretex" film and an inflatable bladder. When inflated, the bladder forms seals at the wrists and neck and provides an insulating dead-air space between the body and the water barrier layer. The garment also has a high temperature resistant aramid outer coverall for fire protection. It is currently in a prototype status.

D1 – CWU-21/P Anti-Exposure Assembly

The outer coverall (CWU-21/P) is constructed of cotton "Ventile" fabric. Neck and wrist seals and joint inserts at the elbows and knees are fabricated of chloroprene coated nylon stretch fabric. It is a one-piece full body garment with an entry zipper across the upper chest and a relief portal zipper at the crotch, both of which are waterproof. Attached socks are fabricated of cotton flocked rubber. The liner (CWU-23/P) is fabricated of two layers, an inner layer of 100 percent cotton and an outer layer of polypropylene netting. It is a one-piece full body garment with a center front entry zipper. Both garments are available in twelve sizes.

D2 – MK-10 British (RAF) Immersion Aircrew Coverall

This coverall is manufactured from two layers of "Ventile" cotton fabric and has a waterproof front entry slide fastener which runs from the right shoulder to the left hip. To assist donning, the back length may be extended by means of a gusset, which is set into the back of the waist and covered by a slide fastener. A convoluted rubber neck seal with a nylon insert and rubber wrist seals prevent water entry in these areas. Waterproof socks constructed of double texture nylon butyl fabric are attached to the leg endings. It is available in nine sizes.

D3 – Swedish A.F. Immersion Suit – Style No. 82

This full body dry suit is fabricated of two layers of cotton "Ventile" fabric and is designed with an integral hood and socks. It is donned through an offset front waterproof slide fastener. The wrists are sealed by rubber wrist seals covered by a "Ventile" fabric oversleeve which is closed with hook and pile. The suit is also equipped with a vent system for the in-flight mode. It is available in ten sizes.

D4 – Canadian MK-1 Constant Wear Immersion Suit

This suit is a one-piece garment made from two layers of cotton "Ventile" fabric. It is a full cut design, shaped at the knees, seat, and arms, with a zipper around the back of the neck from right to left chest. It has a rubber neck seal, wrist seals, and rubber socks to keep the suit watertight. There is also a urination port to give added comfort to the wearer. It consists of a tube of waterproof fabric which is sealed by rolling tightly around a rolling strip, then securing a hook and pile fastener and finally closing a zipper. The suit is designed to be worn with thermal underwear. It is available in ten sizes.

D5 and D6 – NADC Experimental "Goretex" Anti-Exposure Coveralls

These garments are the same design as the CWU-21/P (D1) but are fabricated of different materials. D5 is fabricated of a plain weave high temperature resistant (HTR) aramid/"Goretex"/knit HTR aramid laminate weighing 4.0 oz/yd^2. D6 is fabricated of a twill weave HTR aramid/"Goretex"/knit HTR aramid laminate weighing 6.5 oz/yd^2. The socks on both garments are fabricated of the same cotton flocked rubber as D1. The wrist and neck seals are fabricated of polychloroprene coated nylon. These garments are prototypes.

D7 – Danish Flyer's Anti-Exposure Coverall

This dry suit is fabricated of two layers of specially woven impregnated cotton and is a full body garment designed to allow penetration of water vapor but to prevent water penetration during immersion. Suit entry is through an offset front waterproof slide fastener which goes through the neck seal. Neoprene wrist seals and flocked rubber socks are attached. A neoprene neck seal is fitted to the individual user at issue. Two-piece quilted underwear, fabricated of a cotton cambric sandwich with wool lining, is designed for use with the coverall. It is available in ten sizes.

D8 – Japanese Anti-Exposure Suit

This full length dry suit is fabricated of two layers of cotton "Ventile" material and is donned through a center front waterproof slide fastener which goes through the neck seal. It uses wrist, neck, and ankle seals to prevent water entry and is used with separate pull-over hood and mittens. The seals are fabricated of a rubber-coated stretch fabric. The mittens and hood are fabricated of two layers of cotton "ventile" cloth with an insulating layer sandwiched between. The material of the insulating layer is unknown. The hood has a stretch rubber coated fabric insert at the front neck for fit. It is available in five sizes.

In order to ensure that the true effects of the entire complement of flight clothing and equipment would be measured, each garment configuration was worn with the MA-2 torso harness, the SV-2 survival vest with LPA-2 life preserver, the CSU-15/P Anti-G Garment, a flight helmet, flight gloves and flight boots. Additionally, the undergarments specified for use by the manufacturer were worn. In cases where no undergarments were specified, one or two sets of thermal underwear were worn depending on the design and intended use of the specified configuration. Suits which did not provide full body coverage or which were fabricated of flammable materials were worn with an aramid coverall as presently used in the Fleet. Table IV provides a detailed listing of the garments and flight gear worn with each configuration and the donning sequence. Note that two of the configurations, WF1 and WF2, used two different donning sequences for the mobility and reach measurements.

PHYSIOLOGICAL TESTING

TEST PHASES AND SUBJECT SELECTION

The four phases of physiological testing conducted were: (1) mobility and reach, (2) heat stress/comfort, (3) immersion hypothermia in 7.2°C water, and (4) immersion hypothermia in 0°C water. These phases were conducted sequentially as listed in order to reduce the number of configurations being tested in the more physically demanding tests.

Three garment configurations were eliminated from the program during or prior to mobility testing. The Mustang Survival Suit (WF7) was found to be incompatible with required flight gear due to excessive bulk. The Imperial "Bubble" Suit (D11) was fitted to three subjects but due to extreme discomfort in the neck seal area, mobility measurements could not be completed. The NADC Experimental "Goretex" Coverall (D5) fabricated with plain weave aramid fabric was not measured because its design is identical to D6, with the type of fabric weave being the only difference. The Imperial Survival Suit (D12) was not measured because it is not intended for constant wear use. The remaining 17 configurations were all measured for mobility loss. WF1 and WF2 were measured both inside and outside of the torso harness.

Table IV. Garments/Flight Gear Worn With Each Configuration and Donning Sequence

	WF1 IN	WF1 OUT	WF2 IN	WF2 OUT	WF3	WF4	WF5	WF6	WF7		W1	W2	W3		DI1	DI2	DI3		D1	D2	D3	D4	D5	D6	D7	D8
COTTON UNDERWEAR					X																					
ANTI-EXPOSURE CONFIGURATION					X								X													
1 SET ARAMID THERMAL UNDERWEAR	X	X	X	X	X	X	X	X			X				X		X		X						X	
2 SETS ARAMID THERMAL UNDERWEAR									X			X	X			X				X	X	X	X	X		X
WOOL SOCKS	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X		X	X	X	X	X	X	X	X
ANTI-EXPOSURE CONFIGURATION						X	X	X	X			X			X	X	X		X	X	X	X	X	X	X	X
CWU-27/P ARAMID COVERALL	X	X	X	X	X						X		X						X	X	X	X			X	X
ANTI-EXPOSURE CONFIGURATION	X		X																							
CSU-15/P ANTI-G GARMENT	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X		X	X	X	X	X	X	X	X
MA-2 TORSO HARNESS	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X		X	X	X	X	X	X	X	X
ANTI-EXPOSURE CONFIGURATION		X		X																						
SURVIVAL VEST WITH LPA	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X		X	X	X	X	X	X	X	X
APH-6 HELMET	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X		X	X	X	X	X	X	X	X
FLIGHT GLOVES	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X		X	X	X	X	X	X	X	X
FLIGHT BOOTS	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X		X	X	X	X	X	X	X	X

A total of fourteen suits were evaluated during the heat stress testing. Of these, five suits (D2, D5, D6, D7 and D13) underwent only a limited number of runs due to delayed availability for the program. Three other suits, which were measured for mobility loss (D3, D4 and D8), were planned for inclusion in this phase but had not been received through procurement channels at the time of the testing. Two of these suits (D4 and D8) were included in the 7.2°C immersion hypothermia testing. Since their performance during this testing was not unusual, and their basic design and materials were similar to D2 and D7, no attempt was made to obtain specific heat stress data for these configurations. Another garment which was not included during the heat stress phase was the Australian UVic Flight Jacket (WF2). This jacket was eliminated since it was available in only two sizes and was similar to the Mustang UVic Jacket (WF1), which was available in a full range of sizes. The WF1 jacket was tested both inside and outside of the torso harness. The Imperial Survival Suit (D12) again was not included, since it is not intended for constant wear use.

At the initiation of the 7.2°C immersion hypothermia testing, it was imperative that the number of garments in the program be reduced due to limitations on subject availability and time constraints. At this point, several garments were eliminated for the following reasons. The Parkway One and Two Piece Wet Suits (WF4 and WF5) were eliminated due to their very poor performance in the heat. The CWU-48/P Knit Coverall (W2) was eliminated due to its similarity to the baseline configuration (W1). D5 was eliminated due to its similarity to D6. The ILC Vari-Temp Tube Suit (W3) was eliminated due to mobility restriction. The Swedish A.F. Immersion Suit (D3) was eliminated since only a limited number of suits were available and it was similar to D2, D4, D7 and D8. In addition, its design included an attached hood, which was expected to be unacceptable to the user, and a ventilation system which would not be usable in some aircraft types. The CWU-33A/P Coverall (WF6) which should have been eliminated due to both poor performance in the heat and for excessively restricting mobility, was included in the immersion hypothermia testing since it is still in widespread use by the Fleet. With these eliminations, the cold water testing was reduced to evaluating eleven suits. The Imperial Survival Suit (D12) was not tested because revisions to the original Operational Requirement established separate parameters for testing of Quick Donning Configurations, and it was planned for testing under a separate program.

For the 0°C immersion hypothermia tests, it was desirable to reduce the number of configurations to a maximum of six. Since all of the configurations tested in 7.2°C water, except W1, met the Operational Requirements, some other criteria had to be used for selection. Since the two-layer "dry" configurations maintained higher levels of mean skin temperature than the other configurations, three of them (D2, D4, and D7) were kept in the test program. D8 was retained because of the uniqueness of its design. Of the wet foam (WF) configurations, WF6 was included for data on a full coverage configuration and WF1 was tested for data on the jacket approach. W1 was not included since it did not provide sufficient protection in 7.2°C water.

The subjects were selected from male and female volunteer military personnel who ranged from the 1st to the 98th percentile for height and weight based on 1964 data for U.S. Navy males(2). Each subject was measured, unclad, to determine his or her basic body anthropometry. The following measurements were made according to the procedures described in Appendix A.

- Weight
- Stature (Height)
- Crotch Height
- Sitting Height
- Functional Reach
- Sleeve Inseam Length

Neck Circumference
Chest Circumference
Waist Circumference
Hip Circumference
U. Thigh Circumference
Ankle Circumference
Biceps Circumference (relaxed)
Wrist Circumference
Vertical Trunk Circumference (standing)

The classification of these measurements by percentile, for both male and female subjects, was based on 1964 data for U.S. Navy males and is provided in table V. Tables VI through IX provide information on the subjects who were selected for the individual test phases and the specific garment configurations they tested.

Table V. Subject Anthropometry (%ile)

Ss	Subject Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Sex	M	M	F	M	M	M	M	F	M	M	M	M	M	M	M	M	F	M	M	M
Configurations	Weight	10	5	5	50	63	98	9	8	98	33	48	2	58	<1	85	<1	<1	27	20	59
	Stature	8	38	13	85	38	98	15	13	83	15	54	25	96	<1	24	<1	<1	7	77	69
	Crotch Height	8	15	3	93	40	93	45	8	63	35	35	47	59	4	15	2	<1	4	29	41
	Sitting Height	25	95	23	93	75	99	25	35	85	15	59	39	65	8	93	<1	<1	35	12	59
	Functional Reach	40	15	3	45	25	65	5	<1	20	20	40	<1	85	<1	<1	15	<1	3	3	<1
	Sleeve Inseam	20	60	40	60	40	78	95	40	>99	60	99	>99	>99	77	20	96	40	99	>99	>99
	Neck Circumference	45	20	<1	20	30	90	5	<1	90	20	70	10	70	6	90	6	<1	56	70	70
	Chest Circumference	10	10	<1	28	35	93	3	<1	63	15	63	2	61	<1	87	<1	<1	20	7	62
	Waist Circumference	8	15	<1	15	40	97	15	<1	98	57	96	27	58	4	67	<1	<1	41	21	64
	Hip Circumference	3	4	43	48	58	93	10	38	88	33	93	27	39	2	15	1	14	79	4	43
	Upper Thigh Circumference	10	15	65	13	60	88	3	45	40	15	94	6	15	5	87	4	7	47	24	18
	Ankle Circumference	20	3	20	78	90	98	40	40	75	10	>99	8	>99	90	99	9	3	77	70	89
	Biceps Cirmunference	8	1	<1	8	23	30	1	<1	15	10	10	1	17	2	63	<1	<1	<1	17	7
	Wrist Circumference	85	25	<1	55	85	99	25	2	95	25	26	25	25	2	95	7	<1	55	55	55
	Vert. Trunk Circumference	3	18	<1	80	25	94	1	<1	93	1	96	38	85	11	95	<1	<1	55	31	84

Table VI. Mobility Measurement – Subject Assignment

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Subjects	Subject Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Sex	M	M	F	M	M	M	M	F	M	M	M	M	M	M	M	M	F	M	M	M
	Height %ile	8.0	38.0	13.0	85.0	38.0	98.0	15.0	13.0	83.0	15.0	54.0	25.0	96.0	1.0	24.0	<1	<1	27	20	59
	Weight %ile	10.0	5.0	5.0	50.0	63.0	98.0	9.0	8.0	98.0	33.0	48.0	2.0	58.0	1.0	85.0	<1	<1	7	77	69
	Mean Body %ile	16.5	18.7	11.8	51.5	47.2	91.1	16.0	14.5	76.2	23.3	67.2	19.8	62.9	9.5	64.2	3.9	2.6	38.9	33.6	55.4
Configurations	WF1 In	X	X	X	X	X		X	X		X										
	WF1 Out		X					X					X	X	X						
	WF2 In		X	X	X						X										
	WF2 Out				X	X							X	X							
	WF3	X	X	X	X	X	X	X	X		X										
	WF4	X	X	X	X	X	X	X			X										
	WF5	X	X	X	X	X	X	X			X										
	WF6	X	X		X	X		X			X										
	W1	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
	W2	X	X	X	X	X	X	X	X	X	X										
	W3	X	X	X	X	X		X			X										
	DI 3		X					X			X		X	X							
	D1		X	X	X	X		X			X										
	D2							X			X	X			X						
	D3		X	X				X				X									
	D4		X	X				X			X	X		X							
	D5 & D6											X	X	X	X						
	D7		X	X				X			X		X		X						
	D8		X					X			X	X	X		X						

Table VII. Heat Stress – Subject Assignment

	Subject Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Subjects	Sex	M	M	F	M	M	M	M	F	M	M	M	M	M	M	M	M	F	M	M	M
	Height %ile	8.0	38.0	13.0	85.0	38.0	98.0	15.0	13.0	83.0	15.0	54.0	25.0	96.0	1.0	24.0	<1	<1	27	20	59
	Weight %ile	10.0	5.0	5.0	50.0	63.0	98.0	9.0	8.0	98.0	33.0	48.0	2.0	58.0	1.0	85.0	<1	<1	7	77	69
	Mean Body %ile	16.5	18.7	11.8	51.5	47.2	91.1	16.0	14.5	76.2	23.3	67.2	19.8	62.9	9.5	64.2	3.9	2.6	38.9	33.6	55.4
Configurations	WF1 In	X	X	X				X		X	X									X	X
	WF1 Out	X	X	X				X		X	X									X	X
	WF3	X	X	X				X		X	X									X	X
	WF4	X	X	X				X		X	X									X	X
	WF5	X	X	X				X		X	X									X	X
	WF6	X	X	X				X		X	X									X	X
	W1	X	X	X				X		X	X									X	X
	W2	X	X	X				X		X	X									X	X
	W3	X	X	X				X			X									X	X
	DI 3							X			X							X	X		
	D1	X	X	X				X		X	X									X	X
	D2							X			X							X	X		
	D5		X					X			X										
	D6		X					X			X							X	X		
	D7		X					X			X										
	2 Layer Goretex							X			X							X	X		

Table VIII. Immersion Hypothermia (7.2°C Water) – Subject Assignment

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Subjects	Subject Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Sex	M	M	F	M	M	M	M	F	M	M	M	M	M	M	M	M	F	M	M	M
	Height %ile	8.0	38.0	13.0	85.0	38.0	98.0	15.0	13.0	83.0	15.0	54.0	25.0	96.0	1.0	24.0	<1	<1	27	20	59
	Weight %ile	10.0	5.0	5.0	50.0	63.0	98.0	9.0	8.0	98.0	33.0	48.0	2.0	58.0	1.0	85.0	<1	<1	7	77	69
	Mean Body %ile	16.5	18.7	11.8	51.5	47.2	91.1	16.0	14.5	76.2	23.3	67.2	19.8	62.9	9.5	64.2	3.9	2.6	38.9	33.6	55.4
Configurations	WF1							X			X	X			X	X	X	X			
	WF3							X		X		X			X	X		X			
	WF6							X		X		X			X	X		X			
	W1							X		X		X			X	X		X			
	DI 3							X			X	X					X	X			
	D1							X		X					X	X		X			
	D2							X			X	X			X		X	X			
	D4									X	X	X			X	X					
	D6							X			X	X				X	X				
	D7							X		X		X			X	X		X			
	D8							X			X	X			X			X			
												X									

Table IX. Immersion Hypothermia (0°C Water) – Subject Assignment

Subjects	Subject Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Sex	M	M	F	M	M	M	M	F	M	M	M	M	M	M	M	M	F	M	M	M
	Height %ile	8.0	38.0	13.0	85.0	38.0	98.0	15.0	13.0	83.0	15.0	54.0	25.0	96.0	1.0	24.0	<1	<1	27	20	59
	Weight %ile	10.0	5.0	5.0	50.0	63.0	98.0	9.0	8.0	98.0	33.0	48.0	2.0	58.0	1.0	85.0	<1	<1	7	77	69
	Mean Body %ile	16.5	18.7	11.8	51.5	47.2	91.1	16.0	14.5	76.2	23.3	67.2	19.8	62.9	9.5	64.2	3.9	2.6	38.9	33.6	55.4
Configurations	WF1							X					X					X	X		
	WF6							X					X					X	X		
	DI 3							X					X					X	X		
	D2							X					X					X	X		
	D4							X					X					X	X		
	D7							X					X					X	X		

MOBILITY REDUCTION PHASE

PURPOSE AND GENERAL METHODOLOGY

The purpose of this test phase was to provide quantifiable data regarding the decrease in mobility and reach caused by the wearing of the different configurations in a typical ejection seat or fixed seat environment.

In order to assure that the mobility test procedures would be similar to those performed in the past, the Naval Air Test Center Report, "Evaluation of Flight Clothing and Equipment Effects on Pilot Accommodation" and the NASA reference publication 1024, "Anthropometric Source Book" were reviewed. Based on these sources, an anthropometric measuring device with adjustable point-of-reference measuring sites was then constructed. A series of measurements were recorded for each configuration worn by a minimum of four subjects and a maximum of ten subjects, both male and female. Where possible, depending on size availability of each configuration, measurements for each configuration were made on groups of subjects representing the full range of anthropometry.

TEST PROCEDURES

The list of garment configurations measured and subject assignments is provided in table VI. As previously mentioned, each anti-exposure configuration was also worn with the MA-2 torso harness, the SV-2 survival vest with LPA-2 life preserver, the CSU-15/P Anti-G Garment, a flight helmet, and flight boots.

All subjects were measured wearing one set of aramid thermal underwear and the CWU-27/P summer flying coverall along with the additional flight gear listed above. This configuration, coded as W1, was used as the baseline from which mobility loss percentages were calculated.

Four configurations originally procured for the test program were not measured for mobility reduction. WF7 was found to be incompatible with required flight gear due to excessive bulk. D11 was fitted to three subjects but due to extreme discomfort in the neck seal area, mobility measurements could not be completed. D5 was not measured because its design is identical to D6 with the type of fabric weave being the only difference. D12 was not measured because it was not intended for constant wear use during flight.

For each set of measurements, the subject was dressed in the test configuration along with the specified under- and over-garments as listed in table IV. Subjects were then seated in the anthropometric measuring device which was adjusted for them as illustrated in figure B-1 of appendix B.

The following measurements, fully described in appendix B, were then made and recorded.

Forward Reach
Knee Extension
Shoulder Flexion
Elbow Flexion
Neck Dorsal Flexion
Neck Ventral Flexion
Hip Flexion

Shoulder Extension
Torso Torsion
Neck Rotation
Shoulder Abduction
Shoulder Adduction

The measuring device was readjusted as illustrated in Figure B-2 of appendix B and the following measurements were taken.

Ankle Flexion
Ankle Extension

RESULTS AND ANALYSIS

A table of results and a series of bar graphs are contained in Appendix C.

General Body Mobility Loss — In order to determine a ranking of the suit configurations with regard to their general effect on mobility, nine body motions were averaged with equal weighting. The nine body motions used for this determination were forward reach, knee extension, elbow flexion, torso torsion, neck rotation, shoulder flexion, shoulder extension, shoulder abduction and shoulder adduction. Ankle motions, neck flexion and hip flexion were not included in this determination since no consistent effects caused by the different configurations were evident for these body movements. Mobility reductions for the body in general ranged from 8.1 to 23.3 percent. As already discussed, the baseline configuration used for determination of these percentage losses consisted of the CWU-27/P summer flying coverall (W1), 1 set of aramid thermal underwear, an anti-g garment, a torso harness, a survival vest with LPA, a flight helmet, flight gloves, wool socks and flight boots.

Trends by type of suit were not evident but rather the suit types were interspersed throughout the range. Two of the suits (WF1 and WF2), which are jacket designs, were measured when worn both inside and outside of the torso harness. Mobility was considerably improved when these jackets were worn outside of the torso harness. The 3 least mobile configurations in general were the Mustang UVic Jacket worn inside the torso harness (WF1), the ILC Vari-Temp Tube Suit (W3) and the CWU-33A/P Coverall (WF6). They exhibited mobility reductions of 23.3 percent, 22.4 percent and 18.5 percent respectively over the baseline configuration (W1). Eight configurations exhibited mobility losses of approximately 10 percent or less. They are listed as follows in the order of most mobile to less mobile.

Parkway Two-Piece Full Wet Suit (WF5) — 8.1 percent
Parkway Surfer Shorty Suit (WF3) — 8.1 percent
MK-10 British Immersion Coverall (D2) — 8.5 percent
NADC "Goretex" Coverall (D6) — 8.7 percent
Japanese Anti-Exposure Suit (D8) — 8.8 percent
CWU-48/P Knit Aramid Coverall (W2) — 10.2 percent
Australian UVic Jacket worn outside of the torso harness (WF2) — 10.4 percent
Mustang UVic Thermofloat Jacket (WF1) — 10.5 percent

The remaining configurations exhibited losses ranging from 11.1 to 15.3 percent.

One body motion in particular, that of torso torsion, was greatly reduced by almost all of the configurations. To eliminate its effect on the general ranking of configurations, an additional mean of the other motions was determined without including torso torsion. In this determination, only 4 configurations showed general body mobility losses above 10%. They were the ILC Tube Suit (W3) — 19.1 percent; the Mustang UVic Jacket worn inside the torso harness (WF1) — 18.2 percent; the CWU-33A/P Coverall (WF6) — 15.5 percent; and the Canadian MK-1 Immersion Suit (D4) — 11.6 percent.

General Shoulder Mobility Loss — In order to rank the anti-exposure configurations with regard to their general effect on shoulder mobility, four shoulder movements were averaged with equal weighting. Once again, the CWU-27/P Flying Coverall configuration (W1) was used as a baseline from which mobility reductions were measured. The four shoulder motions used for this determination were flexion, extension, abduction and adduction. General shoulder mobility losses ranged from 6.0 to 25.9 percent. Once again, trends by type of suit were not evident and shoulder mobility of the two jacket designs (WF1 and WF2) was improved when they were worn outside of the torso harness. The three least mobile configurations were again W3, WF6, and WF1 worn inside the torso harness with losses of 25.9 percent, 23.9 percent and 23.2 percent respectively. Nine configurations exhibited losses of approximately 10 percent or less and they were as follows:

MK-10 British Coverall (D2) — 6.0 percent
Two-Piece Wet Suit (WF5) — 7.2 percent
Swedish Immersion Suit (D3) — 7.2 percent
Surfer Shorty Suit (WF3) — 7.3 percent
Japanese Suit (D8) — 7.3 percent
CWU-48/P Knit Coverall (W2) — 8.1 percent
Danish Coverall (D7) — 9.4 percent
Mustang UVic Jacket worn outside of the torso harness (WF1) — 10.5 percent

The remaining configurations exhibited losses ranging from 10.9 to 16.7 percent.

Individual Body Movements

Forward Reach — For this critical body movement, loss of maximum forward reach ranged from 1.9 to 15.2 percent. In terms of actual distance, this translates to a mean loss of from 0.8 to 6.5 inches. Seven configurations decreased maximum forward reach capability by 10 percent or more (4.5 inches or more). These configurations are:

MK-10 British Coverall (D2) — 15.2 percent
Tube Suit (W3) — 14.5 percent
AE2 Coverall (D13) — 13.5 percent
CWU-33A/P Coverall (WF6) — 12.9 percent
Mustang Jacket worn inside the torso harness (WF1) — 12.5 percent
Japanese Suit (D8) — 11.2 percent
Danish Coverall (D7) — 10.5 percent

The five least restrictive configurations were:

Two-Piece Full Wet Suit (WF5) — 1.9 percent
Australian Jacket worn outside of the torso harness (WF2) — 2.2 percent
Australian Jacket worn inside of the torso harness (WF2) — 3.3 percent
Mustang Jacket worn outside of the torso harness (WF1) — 3.7 percent
One-Piece Wet Suit (WF4) — 3.7 percent

The other configurations produced losses in maximum forward reach of from 6.5 to 9.2 percent.

Knee Extension — Knee extension was not greatly affected by any of the configurations. The maximum mobility reduction measured was 7.4 percent with the CWU-33A/P (WF6). Seven configurations had no effect on this movement at all.

Elbow Flexion — Losses in elbow flexion capability ranged from 0 to 10.7 percent. Three of the jacket configurations, the Australian jacket worn inside of the torso harness (WF2) and the Mustang Jacket both inside and outside of the torso harness (WF1) were among the most restrictive. They produced reductions ranging from 9.1 to 10.7 percent. When worn outside of the torso harness, the Australian jacket (WF2) was less restrictive with measured mobility loss averaging only 1.7 percent. Also among the more restrictive configurations were the CWU-21/P Assembly (D1) with 9.5 percent and the CWU-33A/P Coverall (WF6) with 7.9 percent. The most mobile configurations were the two piece wet suit (WF5) — 0 percent; the CWU-48/P Coverall (W2) — 0.9 percent; and the Surfer Shorty Suit (WF3) — 1.0 percent.

Torso Torsion: As mentioned previously, torso torsion was the most seriously effected of all the body movements measured. Losses ranged from 14.7 percent to 64.8 percent with most configurations affecting losses of between 25 and 50 percent. Once again, trends by suit type were not evident but the four least restrictive configurations were dry suits:

NADC "Goretex" Coverall (D6) — 14.7 percent
CWU-21/P Assembly (D1) — 16.7 percent
MK-10 British Coverall (D2) — 25.4 percent
Japanese Suit (D8) — 26.3 percent

With regard to torso torsion in general, it should be noted that even with the baseline configuration (W1), the average body rotation capability was only 21 degrees. This limited capability is most likely due to the presence of the torso harness and belts. The addition of any anti-exposure garment increases the severity of this problem, the extent of which depends on the design of the specific garment.

Neck Rotation — Loss of neck rotation capability ranged from 0 to 27.9 percent with most configurations ranging from 8.6 to 11.9 percent. The most restrictive configurations were the Mustang Jacket worn inside the torso harness (WF1) — 27.9 percent; the Tube Suit (W3) — 26.8 percent; and the Canadian Suit (D4) — 17.4 percent. The least restrictive configurations were the CWU-33A/P Coverall (WF6) — 0 percent; the Australian jacket both inside and outside of the torso harness (WF2) — 1.3 and 2.0 percent; the Two-Piece Wet Suit (WF5) — 3.7 percent; the Surfer Shorty Suit (WF3) — 3.8 percent; and the CWU-21/P Assembly (D1) — 4.0 percent.

Shoulder Flexion — For shoulder flexion, loss of mobility ranged from 0 to 36.8 percent. The five least mobile configurations producing losses of approximately 30 percent or more were:

Tube Suit (W3) — 36.8 percent
CWU-33A/P Coverall (WF6) — 34.8 percent
AE2 Coverall (D13) — 32.3 percent
Mustang Jacket worn outside of the torso harness (WF1) — 31.6 percent
Mustang Jacket worn inside of the torso harness (WF1) — 29.5 percent

Among the most mobile garments producing losses of 13.2 percent or less were:

Swedish Suit (D3) – 0 percent
Two-Piece Wet Suit (WF5) – 5.5 percent
NADC "Goretex" Coverall (D6) – 10.7 percent
Japanese Suit (D8) – 11.5 percent
CWU-48/P Coverall (W2) – 13.2 percent
Danish Coverall (D7) – 13.2 percent

Shoulder Extension – Six configurations produced no effect on shoulder extension with the remaining suits decreasing motion from 1.2 to 28.9 percent. The six configurations having no effect were:

Mustang Jacket worn outside of the torso harness (WF1)
Surfer Shorty Suit (WF3)
One-Piece Wet Suit (WF4)
Two-Piece Wet Suit (WF5)
CWU-21/P Assembly (D1)
MK-10 British Coverall (D2)

The Swedish Suit (D3) produced a loss of only 1.2 percent. The most restrictive configurations were the Mustang Jacket worn inside the torso harness (WF1) – 28.9 percent and the Canadian Suit (D4) – 25.1 percent.

Shoulder Abduction – Shoulder abduction was one of the least effected of all the body motions. Seven configurations had no effect and the others ranged from 1.5 to 9.5 percent loss. The least mobile garment was the One-Piece Wet Suit (WF4) with a 9.5 percent loss.

Shoulder Adduction – Loss of shoulder adduction ranged from 0 to 43.5 percent. The least mobile configurations were CWU-33A/P (WF6) – 43.5 percent; the Tube Suit (W3) – 39.1 percent; and the CWU-21/P Assembly (D1) – 34.0 percent. The most mobile garments were the MK-10 British Coverall (D2) – 0 percent; the AE2 Coverall (D13) – 2.8 percent; the CWU-48/P Coverall (W2) – 3.9 percent; and the Mustang Jacket worn outside of the torso harness (WF1) – 5.3 percent. The other configurations' losses ranged from 10 to 28.4 percent with the dry suits (D) doing generally better than the wet foam suits (WF).

SUMMARY

Three configurations were never found among the most mobile and were frequently among the most restrictive. They are the Mustang Jacket inside the torso harness (WF1), the Tube Suit (W3), and the Canadian Suit (D4). Another configuration, consistently listed with the most restrictive was the CWU-33A/P Coverall (WF6).

Those configurations listed as most mobile and never found among the most restrictive include the Two-Piece Wet Suit (WF5), the Surfer Shorty Suit (WF3), the CWU-48/P Coverall (W2), the NADC "Goretex" Coverall (D6), the Australian Jacket outside the torso harness (WF2), and the Swedish Suit (D3). Other Good configurations found among the least mobile only once are the MK-10 British Coverall (D2) and the Japanese Suit (D8).

The remaining configurations were usually in the mid-range for individual movements occasionally being among the best or worst. They include the Mustang Jacket outside the torso harness (WF1), the Australian Jacket inside the torso harness (WF2), the One-Piece Wet Suit (WF4), the CWU-21/P Assembly (D1), the Danish Coverall (D7) and the AE2 Coverall (D13).

HEAT STRESS TEST PHASE

GENERAL PURPOSE AND METHODOLOGY

The purpose of this phase was to provide data on the physiological effects of wearing the different configurations in a moderately warm environment. The task sequence for the test runs included psychomotor tracking tasks, physical work tasks, and rest, in order to include the various activity levels typical of ejection seat, fixed seat, and mobile crewmen.

A 3-hour test run duration was chosen as typical of an average helicopter mission length. The tests were conducted in a thermal chamber with a regulated environment. The ambient temperature in the chamber throughout the test run was maintained at 35°C, which was selected for the following reasons: (1) NATOPS requires use of an anti-exposure garment when the water temperature is 15.6°C or below; (2) since outside air temperature (OAT) changes fairly rapidly to match water temperature, it was assumed that the maximum OAT, when anti-exposure equipment is required, would not exceed 15.6°C; (3) according to data collected for the H-3 helicopter, the helicopter in Navy inventory having the highest ambient temperatures, internal cabin temperature can increase as much as 16.6 to 22.2°C higher than the OAT. The maximum internal cabin temperature would therefore range between 32.3°C and 37.8°C. The helicopter environment was chosen as a baseline since it was assumed to represent the worst case. It was further assumed that the suit configurations would perform better in fixed wing aircraft, where air conditioning is available, but that the relative performance levels of each suit configuration would remain the same.

TEST PROCEDURES

A brief overview of a test run involved weighing a nude subject on a very sensitive beam balance, and application of four thermistor transducers in the area of the chest, upper arm (lateral), lower leg (lateral) and the anteromedial aspect of the upper leg. An appropriate thermistor probe was inserted some 8-10 cm rectally to measure deep body temperature. The subject was then dressed in the clothing assembly of the day including all gear as listed in table IV. Just before entering the test chamber, where an ambient temperature of 35°C had been established, a blood pressure cuff containing an integral pressure transducer was wrapped around the left upper arm for measures of pre-test heart rate and blood pressure. The system used for these measures was the DINAMAP Model 845 and the Model 950 Trend Recorder/Printer. A preliminary scan of the body temperatures was made to assure the working order of the instrumentation.

Immediately upon entering the test chamber, the subject began a 20-minute cycle, which included in the main a 5 minute work task, three separate intervals of a tracking task (Atari), each lasting 2.3 min., and finally a rest period of 6.2 min. The 20-minute cycle was repeated throughout the course of the test run, which was scheduled to last, at the most, for a period of 180 minutes. Figure 4 illustrates one repeat of the test sequence.

The planned psychomotor tracking task consisted of a two-dimensional pursuit tracking task implemented by an Atari Video Computer System. The task to the subject was to align an attack jet with a target jet such that a fired missile would intercept the target. Subjects controlled speed and direction of the attack jet and the time of missile firing, by means of a "joystick" control module. If the missile intercepted the target jet, a hit was scored and the flight directions of both jets were automatically changed to new positions. Prior to the start of the test runs, subjects were trained in the tracking task until their performance leveled off. Although a thorough attempt was made to bring each subject to a plateau level, once the actual test program began individual competition on a day-to-day basis resulted in ever-increasing scores rendering the data non-usable.

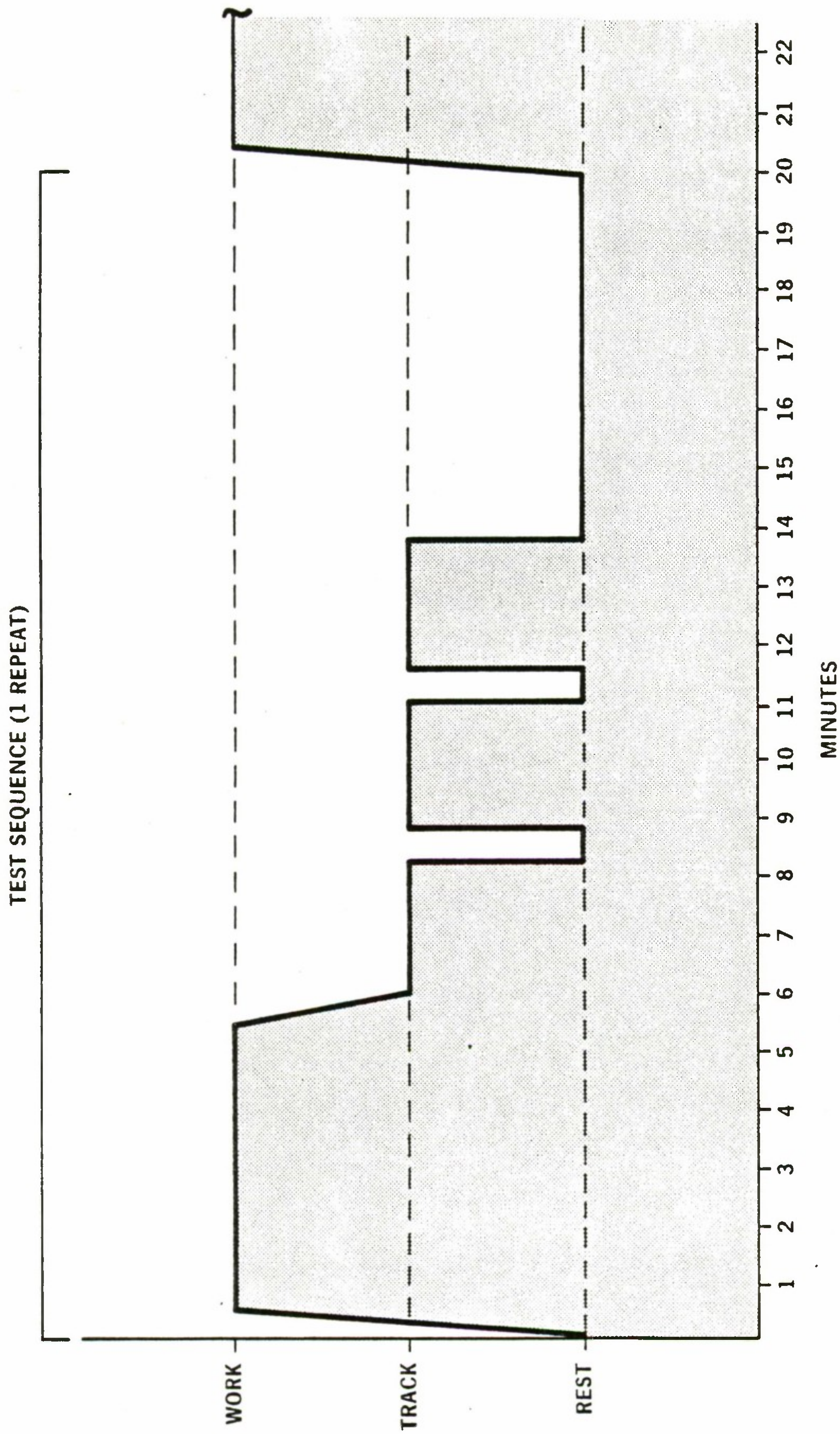

Figure 4. Heat Stress Test Sequence

The work task consisted of carrying a distributed 20-kg load suspended from the shoulders while pacing within the confines of the chamber at a rate of about 1.6 km/hr. The work task was intended to produce a metabolic output of approximately 262W (225 kcal/hr or 900 BTU/hr), which was considered representative of a moderate level work load. The no work phase was designed to represent that of a resting metabolic output.

Heart rate and blood pressure measurements were taken five times throughout the test at 20, 60, 100, 140 and 180 minutes. Core temperature and skin temperatures were recorded every 20 minutes throughout the run. At the end of the test run, either full term (3 hour) or for a shorter period, following the attainment of subjective or objective endpoints, the subject was aided in the removal of the test clothing, dried with a towel and weighed once again on the balance. In the event that the rectal probe became dislodged in the course of the test activity, the subject was asked to re-insert it as soon as possible upon leaving the test cell, in order that a measure of deep body temperature could be recorded at the end of the test exposure.

The subjects exercised the right to request termination of runs in less than 3 hours for reasons ranging from extreme discomfort to disorientation and nausea. Objectively, elevated heart rate levels (180 beats/min) (BPM) during the working phase and 140 BPM during the sedentary phase and/or rectal temperature increases to 39°C (or a rate of rise of 1.6°C/hr) were used as tolerance criteria for the termination of runs in less than 3 hours.

Table VII provided a list of the configurations tested and subject assignments for this test phase.

RESULTS AND ANALYSIS

The results of the heat stress test runs are reported in terms of total weight loss (TWL), rectal temperature rise (ΔT_{RE} in °C/hr.) and index of strain (I_S). Table X provides a ranking of the configurations according to the mean response of each parameter in question. The configurations are ranked in a decreasing order of the severity of response for each parameter considered. The standard deviation for each mean value is also shown.

1. Total Weight Loss (TWL) – The observations regarding TWL in grams/minute ranged from a mean of 1.98 with the NADC Experimental "Goretex" Coverall (Plain Weave) (D5) to 8.09 using the Parkway Two-Piece Wet Suit (WFS). Reference to the ranking of all suits regarding TWL indicates that the wet foam suit types (WF) evoked an increase in TWL over the CWU-27/P Summer Flight Coverall (WI) by a factor of two to one. Subjects wearing the Danish Coverall (D7) and the British Coverall (D2) as well as the three "Goretex" configurations (D5, D6 and D13) exhibited lower TWL than the summer flight coverall (WI). However, this data is for a reduced number of test runs, so it may not be directly comparable to other configurations.

2. Rectal Temperature Rise – The rise in rectal temperature (ΔT_{RE} in °C/hr.) ranged from 0.02 for the Summer Flight Coverall (WI) to 0.38 for the Two-Piece Wet Suit (WFS). The relative suit ranking reveals that the WF suits produced increases in T_{RE} greater by a factor of at least six over those values measured for the Summer Flight Coverall (WI). The level of rectal temperature attained during all heat exposure test runs was below the predetermined limit of 39°C that would have dictated early termination.

Table X. Physiological Responses of Active Subjects Wearing Different Suit Assemblies in a Warm Environment

TWL (g/min)			ΔT_{RE} in °C/hr			I_S*		
Suit	Mean	SD	Suit	Mean	SD	Suit	Mean	SD
WF5	8.09	1.55	WF5	0.38	0.07	WF5	1.99	0.19
WF4	7.35	1.85	WF4	0.30	0.04	WF4	1.79	0.22
WF6	6.70	1.27	WF6	0.21	0.07	WF6	1.62	0.18
WF1 in	6.18	1.60	WF1 in	0.18	0.13	WF1 in	1.58	0.33
WF3	5.88	1.11	WF3	0.18	0.08	WF3	1.49	0.19
W3	5.10	2.39	D5	0.18	0.07	WF1 out	1.39	0.12
WF1 out	5.01	0.26	WF1 out	0.15	0.04	D1	1.31	0.11
D1	4.38	0.72	W3	0.13	0.07	W3	1.29	0.18
W1	4.04	0.71	DI3	0.12	0.03	DI3	1.16	0.16
W2	3.88	0.62	D1	0.11	0.03	D2	1.16	0.16
D7	2.65	0.66	D2	0.11	0.05	D7	1.14	0.05
D2	2.37	0.16	D7	0.09	0.02	W2	1.13	0.06
DI3	2.15	0.30	D6	0.08	0.09	W1	1.12	0.11
D6	2.04	0.20	W2	0.07	0.04	D5	1.10	0.20
D5	1.98	0.42	W1	0.02	0.04	D6	1.04	0.15

$$*I_S = \frac{HR}{100} + \Delta T_r + TWL$$

where:

- HR = terminal heart rate (beats/min.)
- ΔT_r = increase in rectal temp (°C/hr.)
- TWL = total weight loss (Kg/hr.)

3. Index of Strain (I_S) – The index of strain is a measure of evaluated stress rated from 1.0 to 4.0 using the formula, ...

$$I_s = \frac{H_r}{100} + \Delta T_r + TWL$$

where

I_s = index of physiological strain

H_r = terminal heart rate

ΔT_r = rise in rectal temperature in °C/hr

S_r = sweat production (nude weight loss in kg/hr)

The above formulation, taken from Air Force Pamphlet 161-16 (1968), has been used to define human performance and tolerance limits in heat and to assess the effectiveness of ventilated or non-ventilated clothing in protecting against heat. In using this formula, an index of 1.0 to 1.5 indicates low thermal strain with indefinite tolerance; 1.5 to 2.0 represents mild strain with a tolerance time exceeding three hours; and an index of 2.0 to 2.5 indicates tolerance time will be 3 hours or less. Indices of 3.0 to 4.0 indicate high levels of heat stress which can be tolerated only for one-half to one hour and which represent severe physiological strain.

The configurations tested produced an index of strain which ranged from 1.04 with the NADC Experimental "Goretex" Coverall (Herringbone) (D6) to 1.99 with the Two-Piece Wet Suit (WF5). Comparison of these results with the discussion above indicates that all of the tested configurations are within the limits as determined by the operational requirement (O.R.). The ranking of the configurations indicates that the WF suits produced responses that were greater by a factor of almost two over the responses produced by the Summer Flight Coverall (WI). Again, a lower I_S was indicated using two of the "Goretex" configurations (D5, D6) in a reduced set of exposure trials.

4. Duration of Exposure – Of the 180 test runs in the program, subjects tolerated the full exposure period of 3 hours in 120 cases. In the remaining tests, the duration of exposure was lessened as a result of heat discomfort, headache, impaired circulation, dizziness and an expressed unwillingness to continue in the thermal environment. In none of the tests which were less than 3 hours duration were critical physiological endpoints reached. Within the context of a voluntary duration of exposure, a ranking of the suit assemblies is shown in table XI in order of the number of completed 3-hour tests relative to the number of tests conducted. This data confirms the objective data already discussed and indicates generally less willingness of subjects to continue for the full duration of exposure in the WF suits than in the other configurations tested.

5. Discussion and Conclusions – Generally, the observations regarding the physiological parameters considered indicated that the wet foam (WF) suit configurations evoked more pronounced responses than the remainder of the suits tested. For all physiological parameters considered, the most extreme responses were elicited by the following suits in a decreasing order of severity:

WF5	Two-piece wet suit
WF4	One-piece wet suit
WF6	CWU-33A/P
WF1 in	Mustang UVic Jacket worn inside the torso harness
WF3	Surfer Shorty Suit.

Table XI. Distribution of Heat Stress Tests According to Voluntary Duration of Exposure for Each Clothing Assembly

Assembly	Total Runs	Exposure Time (Hr)* 3	2 2/3	2 1/3	2	1 2/3	1 1/3	1	Percent Lasting 3 hours
WF5	16	2	1	1	2	6	3	1	12.5
WF4	16	5	–	1	3	4	2	1	31.2
WF1 in	16	6	–	3	–	4	3	–	37.5
WF6	16	10	–	–	1	4	–	1	62.5
W3	14	9	–	1	3	–	–	1	64.2
WF3	16	11	–	1	3	1	–	–	68.8
D1	16	11	–	–	1	2	2	–	68.8
WF1 out	16	13	1	1	–	1	–	–	81.2
D7	6	5	–	–	1	–	–	–	83.3
D5	3	3	–	–	–	–	–	–	100
D2	4	4	–	–	–	–	–	–	100
DI3	4	4	–	–	–	–	–	–	100
D6	7	7	–	–	–	–	–	–	100
W2	15	15	–	–	–	–	–	–	100
W1	15	15	–	–	–	–	–	–	100

*nearest 1/3 of an hour

Within the limits of the experimental program, none of the tests conducted were terminated for reasons of attaining critical physological endpoints in less than the 3-hour planned duration. Tests of less than 3 hours were terminated for subjective sensations related to heat discomfort, as noted heretofore. However, it should be noted that the Two-Piece Wet Suit (WF5) and the One-Piece Wet Suit (WF4) resulted in rates of total weight loss (as much as 10 gm/min in some test runs) which would be expected to compromise the physiological well-being of a segment of the population if the duration of the exposure were extended to 3 hours. In addition, while using the Two-Piece Wet Suit (WF5), the rate of rectal temperature rise (Δ T_{RE}) would have been expected to approach a critical level of 39°C, if tests had been extended to a period of 3 hours. From the subjective standpoint, the wet foam (WF) suits were least acceptable under the conditions tested, as indicated by the high number of tests terminated voluntarily in less than 3 hours. Among the full coverage wet foam suits, the CWU-33A/P was slightly more acceptable, as evidenced by (a) the percentage of voluntary completions of the 3-hour testing period, and (b) the lower rates of weight loss, rectal temperature rise, and index of strain as compared to WF4 and WF5.

IMMERSION HYPOTHERMIA PHASE

PURPOSE AND GENERAL METHODOLOGY:

The purpose of this test phase was to provide data on the relative thermal protection performance of the various configurations. Two levels of exposure were evaluated in accordance with the Navy Operational Requirement. The first test level was conducted in 7.2° C water with 0° C air and 24-32 kph winds. The second level was conducted in 0-1.7° C water with -6.7° C air and 24-32 kph winds.

A 120-minute test run duration was chosen in accordance with the Operational Requirement and in consonance with the current Navy SAR goal. The tests were conducted in a thermal chamber with a pool which could be maintained at the specified environmental levels.

TEST PROCEDURES:

The procedure for each test run was as follows. The nude subject was first weighed on a very sensitive beam balance. Following this, thermistor transducers were applied at the following body locations: Forehead, nape of the neck, upper arm (lateral), lower arm (anterior), pad of the index finger, mid-line of the chest, upper back, lower back, upper leg (medial), lower leg (lateral), instep of the foot, and pad of the great toe. In addition, an appropriate thermistor probe was inserted 8-10 cm. rectally to measure deep body temperature. The subject was then dressed in the test configuration of the day including all over- and under-garments listed in table IV.

Prior to entering the test chamber, where the water and ambient temperatures had been pre-established, a scan of the subject's skin and core temperatures was taken and recorded. Immediately upon entering the test chamber, the subject entered the water, immersing his entire body. A scan of skin and core temperatures was again made and recorded at this time. For the 7.2° C water tests, the subject remained in the water for the duration of the run. For the 0° C water tests, the subject remained in the water for a period of 10 minutes. After this, he boarded a one-man raft, unassisted, bailed the raft of excess water, and then donned protective mittens and hood. The subject remained in the raft for the duration of the run.

Rectal core temperature was monitored visually throughout the runs and was recorded along with the various surface skin temperatures every 10 minutes. At the end of each test run, either full term (120 minutes) or for a shorter period, following the attainment of subjective or objective end-points, the subject was aided in exiting the chamber and in the removal of all supplemental clothing except the test configuration. A scan of temperatures was recorded at the termination of the run. The subject was then rewarmed in a controlled temperature water bath, while continuing to monitor core temperature. Post-test nude weight was recorded following the rewarming.

Subjectively, the subject had the right to terminate the test run in less than 120 minutes. Objectively, a rectal temperature decrease to 35° C or any skin temperature decrease to 0° C were used as tolerance criteria for termination in less than 120 minutes.

Tables VIII and IX provided a list of the configurations tested at each water temperature and subject assignments.

RESULTS AND ANALYSIS

The results of the immersion hypothermia testing will be discussed in terms of rectal temperature (T_{RE}), mean skin temperature (MST) and duration of exposure. The two test phases (7.2°C and 0°C water) will be discussed separately.

1. 7.2°C Water Testing

a. Duration of Exposure – Of the 113 test runs in this phase, subjects tolerated the full exposure period of 120 minutes in 17 cases and tolerated exposure periods of 60 minutes or more in 57 cases. In none of the tests that were less than 120 minutes duration were critical physiological endpoints reached. Table XII provides a ranking of the suit configurations according to the percentage of runs which lasted at least 60 minutes. Information concerning the distribution of runs by duration and the percentage of runs which lasted the full 120 minutes is also provided. This data is important as a measure of subjective acceptance of and/or confidence in the individual configuration. It is not necessarily a measure of the actual protective capability of the configurations.

b. Rectal Temperature (T_{RE}) – The change in mean rectal temperature for the various configurations was evaluated in two ways. Table XIII provides mean rectal temperature changes for those runs which lasted for the full 120 minute duration. With three configurations (W1, D13, and D6) there were no runs which lasted full duration, and three configurations (WF1, D1, and D8) experienced only one run of full duration. The mean change in rectal temperature (ΔT_{RE}) at the end of the full duration runs ranged from +0.1°C for the UVic Jacket (WF1) to -1.0°C for the Japanese Coverall (D8). To increase the data base, runs which lasted a minimum of 60 minutes were evaluated along with the 120-minute runs, extrapolating the data for the shorter runs. Table XIV provides the resulting data for the actual and extrapolated 120-minute runs. Data for the Summer Flying Coverall (W1) was considered insufficient for reliable extrapolation since the longest runs were only 60 minutes. Data for D13 and D6 was based on extrapolation only since no 120-minute runs were made. The mean change in rectal temperature at the actual and extrapolated 120-minute endpoint of the runs ranged from -0.2°C for the NADC "Goretex" Coverall (D6) and the Danish Coverall (D7) to -0.7°C for the British Coverall (D2) and the Japanese Coverall (D8). The change in mean rectal temperature was not significant for any of the configurations. All of the configurations indicated rectal temperature endpoints, after 120 minutes of exposure, which would be well above the 35°C cut off established by the Operational Requirement. Figure 5 graphically illustrates the data of Table XIV.

c. Mean Skin Temperature (MST) – The change in mean skin temperature (Δ MST) for the various configurations was evaluated in the same way as the rectal temperature change. Table XV provides data for the actual 120 minute runs and table XVI provides data for the actual and extrapolated 120-minute runs. For the actual 120-minute runs, Δ MST ranged from -8.1°C for the Danish Coverall (D7) to -15.1°C for the Surfer Shorty Suit (WF3). The Δ MST for the actual and extrapolated runs ranged from -8.4°C for the ILC "Goretex" Coverall (D13) to -15.2°C for the CWU-33A/P Coverall (WF6). Although no specific requirement for mean skin temperature is cited in the Operational Requirement, Δ MST is important since greater drops in skin temperature decrease the wearer's comfort and mobility and can have a negative psychological effect on his feelings about his survival potential. Figure 6 graphically illustrates the data from table XVI. In general, the two-layer "dry" configurations (D2, D4, D7 and D8) and the ILC AE2 Coverall (D13) performed better than the remainder of the configurations tested.

Table XII. Duration of Test Runs in 7.2°C Water

	10	20	30	40	50	60	70	80	90	100	110	120	% RUNS < 60 MIN.	% RUNS 60-120 MIN.	% RUNS TO 120 MIN.
07						1	1	2		1		4	0.0	100.0	44.4
04				1		3	2		1			2	11.1	88.9	22.2
WF3		1	1	1	1	2	1	2				3	33.3	66.7	25.0
02					3	2						3	37.5	62.5	37.5
01			-1	3	1	3	1					1	50.0	50.0	10.0
06			1	2	2	2	2			1			50.0	50.0	0.0
013				1	3	3	1						50.0	50.0	0.0
WF1			3	3	1	2		2				1	58.3	41.7	8.3
08			1	1	3	1						1	71.4	28.6	14.3
WF6			2	4	2			1				2	72.7	27.3	18.2
W1		5	6	1	2	3							82.4	17.6	0.0

Table XIII. Mean T_{RE} (°C) for Actual 120 Minute Runs in 7.2° C Water

	# OF 120 MIN. RUNS	TOTAL # OF RUNS	% OF 120 MIN. RUNS		PRE-TEST TRE	WATER ENTRY	30 MIN.	60 MIN.	120 MIN.		∆ TRE
WF1	1	12	8.3		37.0	37.1	37.5	37.6	37.1		+0.1
WF3	3	12	25.0		37.2	37.4	37.4	37.2	36.8		-0.4
WF6	2	11	18.2		37.4	37.4	37.6	37.2	37.1		-0.3
W1	0	17	0.0		—	—	—	—	—		—
013	0	8	0.0		—	—	—	—	—		—
01	1	10	10.0		37.3	37.3	37.4	37.3	37.0		-0.3
D2	3	8	37.5		37.3	37.4	37.3	37.1	36.6		-0.7
04	2	9	22.2		37.0	37.3	37.4	37.2	36.9		-0.1
06	0	10	0.0		—	—	—	—	—		—
07	4	9	44.4		37.5	37.6	37.6	37.6	37.3		-0.2
D8	1	7	14.3		36.8	36.9	36.8	36.6	35.8		-1.0

Table XIV. Mean T_{RE} (°C) for Actual and Extrapolated 120 Minute Runs in 7.2°C Water

	# OF ACTUAL 120 MIN. RUNS	# OF RUNS 60-120 MIN.	TOTAL # OF ACTUAL + EXTRAP. RUNS	% OF TOTAL RUNS		PRE-TEST TRE	WATER ENTRY	30 MIN.	60 MIN.	120 MIN.		Δ TRE
WF1	1	4	5	41.7		37.2	37.2	37.4	37.1	36.7		-0.5
WF3	3	5	8	66.7		37.3	37.4	37.5	37.3	36.8		-0.5
WF6	2	1	3	27.3		37.4	37.4	37.5	37.3	36.9		-0.5
W1	0	3	3	17.6		—	—	—	—	—		—
013	0	4	4	50.0		36.8	36.7	36.7	36.5	36.2		-0.6
01	1	4	5	50.0		37.1	37.2	37.2	36.9	36.7		-0.4
02	3	2	5	62.5		37.1	37.2	37.1	36.9	36.4		-0.7
04	2	6	8	88.9		37.1	37.2	37.4	37.2	36.8		-0.3
06	0	5	5	50.0		37.0	37.0	37.1	36.9	36.8		-0.2
07	4	5	9	100.0		37.1	37.2	37.3	37.2	36.9		-0.2
08	1	1	2	28.6		37.1	37.3	37.2	37.1	36.4		-0.7

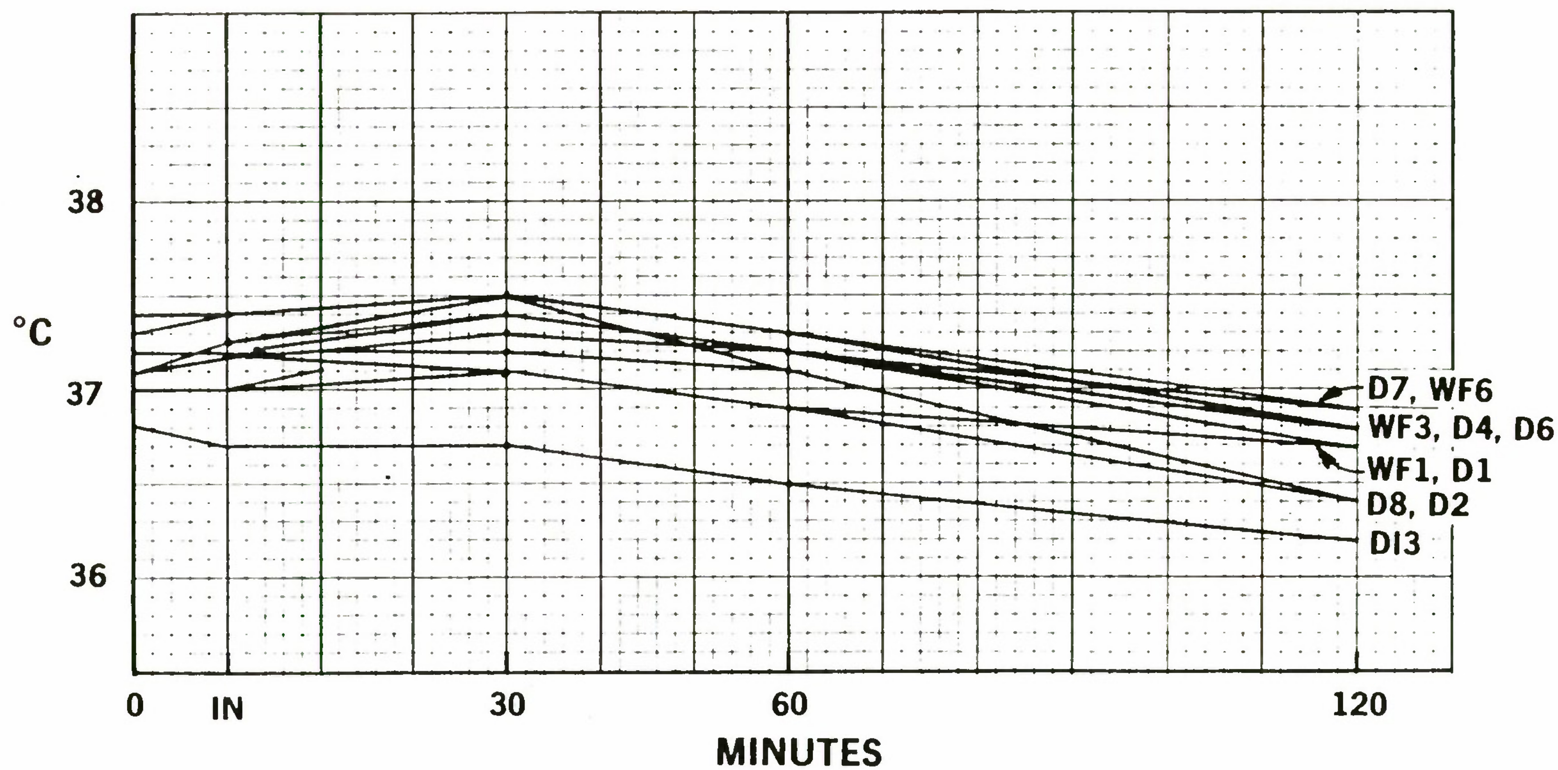

Figure 5. Change in T_{RE} (°C) for Actual and Extrapolated 120 Minute Runs in 7.2°C Water

Table XV. MST (°C) for Actual 120 Minute Runs in 7.2°C Water

	# OF 120 MIN. RUNS	TOTAL # OF RUNS	% OF 120 MIN. RUNS	PRE-TEST MST	WATER ENTRY	30 MIN.	60 MIN.	120 MIN.	Δ MST
WF1	1	12	8.3	32.4	29.3	21.9	20.6	19.3	-13.1
WF3	3	12	25.0	32.9	27.4	22.2	19.2	17.8	-15.1
WF6	2	11	18.2	33.8	30.4	23.6	20.8	19.5	-14.3
W1	0	17	0.0	—	—	—	—	—	—
D13	0	8	0.0	—	—	—	—	—	—
D1	1	10	10.0	33.0	32.1	24.5	21.8	18.8	-14.2
D2	3	8	37.5	31.9	32.9	28.1	25.7	23.3	-8.6
D4	2	9	22.2	32.5	34.0	27.8	25.8	23.2	-9.3
D6	0	10	0.0	—	—	—	—	—	—
D7	4	9	44.4	33.1	33.2	28.0	26.9	25.0	-8.1
D8	1	7	14.3	34.3	32.4	29.1	27.3	23.2	-11.1

Table XVI. MST (°C) for Actual and Extrapolated 120 Minute Runs in 7.2°C Water

	# OF ACTUAL 120 MIN. RUNS	# OF RUNS 60-120 MIN.	TOTAL # OF ACTUAL & EXTRAP. RUNS	% OF TOTAL RUNS	PRE-TEST MST	WATER ENTRY	30 MIN.	60 MIN.	120 MIN.	Δ MST
WF1	1	4	5	41.7	32.8	28.8	22.2	21.2	19.5	-13.3
WF3	3	5	8	66.7	33.0	27.9	21.6	19.4	17.9	-15.1
WF6	2	1	3	27.3	33.5	28.6	22.4	19.9	18.3	-15.2
W1	0	3	3	17.6	—	—	—	—	—	—
D13	0	4	4	50.0	33.3	33.2	29.4	27.7	24.9	-8.4
D1	1	4	5	50.0	33.1	33.1	25.4	22.5	19.8	-13.3
D2	3	2	5	62.5	32.4	33.0	28.5	26.4	23.7	-8.7
D4	2	6	8	88.9	33.2	32.3	27.2	25.0	21.9	-11.3
D6	0	5	5	50.0	33.4	32.3	24.2	22.1	19.3	-14.1
D7	4	5	9	100.0	33.2	33.3	27.4	25.7	23.3	-9.9
D8	1	1	2	28.6	34.1	33.2	28.7	26.6	22.4	-11.7

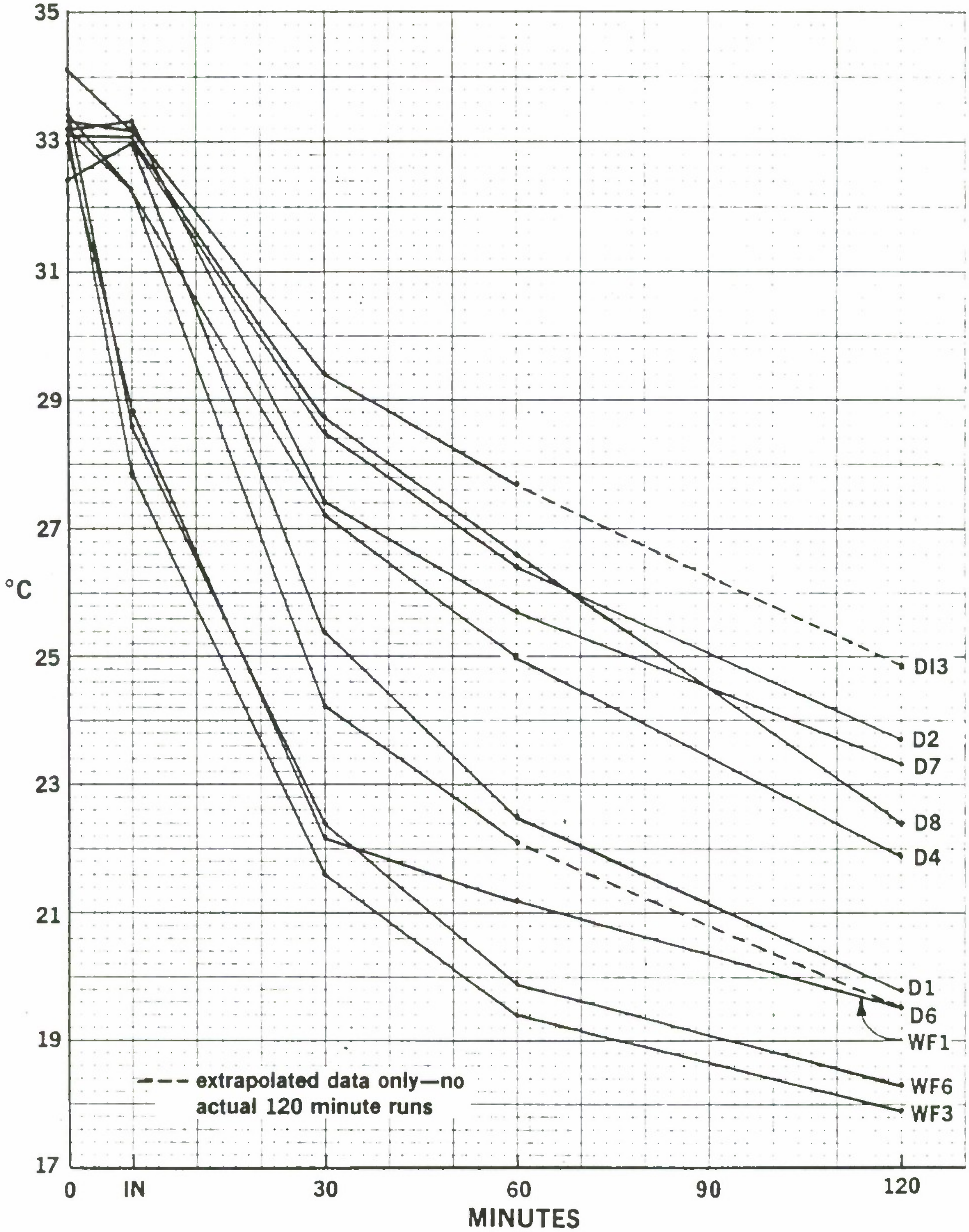

Figure 6. MST (°C) for Actual and Extrapolated 120 Minute Runs in 7.2°C Water

2. 0° C Water Testing

a. Duration of Exposure — Of the 24 test runs in this phase, subjects tolerated the full exposure period of 120 minutes in 19 cases and tolerated exposure periods of at least 60 minutes in all of the remaining runs. In none of the tests, that were less than 120 minutes duration, were critical physiological endpoints reached. Table XVII provides a list of the configurations tested and the distribution of runs by duration. The reasons for early termination included extreme shivering, extreme cold discomfort in the extremities and a questionable rectal core temperature for a subject who was found to be under medication.

b. Rectal Temperature (T_{RE}) — Only those runs which went for the full duration of 120 minutes were evaluated, although the shorter runs appeared to be following the same general trend at the time of termination. Table XVIII provides a summary of the mean rectal temperature changes which occurred during the 120-minute runs. The mean change in rectal temperature (Δ T_{RE}) at the end of the runs ranged from 0.0° C for the UVic Jacket (WF1) to -0.8° C for the CWU-33A/P Coverall (WF6) and the Danish Coverall (D7). The change in mean rectal temperature was not significant for any of the configurations which all produced endpoints well above the preset 35° C cutoff. Figure 7 graphically illustrates the similarity in performance of the configurations tested.

It is of curious interest that the wet foam jacket (WF1) elicited no change in core temperature, as contrasted with the decrease experienced with the remaining configurations. The nature of the wet foam suit is such that the thin film of water between the body and the suit is rapidly heated to body temperature and then provides the body with a blanket of warmth. This type of relationship continues to exist until the insulation material of the suit cools to a sufficient level such that it can no longer provide protection from cooling of the restrained water layer. Had the in-water portion of this phase of testing been extended even as much as 5 minutes, it is highly doubtfull that no decrease in core temperature would have occurred. This can be attributed to the fact that the foam layer of the suit would not have been able to provide sufficient protection for the trapped water layer.

c. Mean Skin Temperature (MST) — The mean skin temperature change was also evaluated only for those runs which completed the full 120-minute duration. Table XIX provides a summary of the results. The Δ MST at the end of the runs ranged from -5.4° C for the ILC AE2 Coverall (D13) to -7.4° C for the CWU-33A/P Coverall (WF6). As with rectal temperature change, there were no significant differences among the configurations nor any dangerously significant drop in skin temperature by any of the individual configurations. Figure 7 illustrates these results.

3. Summary

With the exception of the Summer Flying Coverall (W1), all of the configurations tested in 7.2° C and 0° C water exceeded the requirements of the Navy Operational Requirement for their respective level of protection. Although no significant differences in T_{RE} were shown, differences among the configurations tested in 7.2° C water were evident for change in mean skin temperature (MST). For this parameter, the two-layer "dry" configurations (D2, D4, D7 and D8) and the ILC AE2 Coverall (D13) produced higher endpoint levels for MST than the other configurations. This higher level of MST would most likely result in a greater level of user comfort and a higher user acceptability for these configurations. For the configurations tested in 0° C water, no significant differences were exhibited for either Δ T_{RE} or Δ MST in runs lasting 120 minutes.

Table XVII. Duration of Test Runs in 0°C Water

	20	40	60	80	100	120	
WF1			1	1		2	
WF6				2		2	
DI3				1		3	
D2						4	
D4						4	
D7						4	

Table XVIII. Mean T_{RE} (0°C) for 120 Minute Runs in 0°C Water

	# OF 120 MIN. RUNS	TOTAL # OF RUNS	% OF 120 MIN. RUNS		PRE-TEST TRE	WATER ENTRY	10 MIN. RAFT BOARDING	30 MIN.	60 MIN.	120 MIN.		△ TRE
WF1	2	4	50.0		37.2	37.4	37.4	37.4	37.3	37.2		0.0
WF6	2	4	50.0		37.2	37.4	37.1	37.2	36.9	36.4		-0.8
D13	3	4	75.0		36.9	37.3	37.3	37.3	37.0	36.8		-0.1
D2	4	4	100.0		37.5	37.7	37.8	37.7	37.4	37.1		-0.4
D4	4	4	100.0		37.2	37.3	37.3	37.3	37.0	36.7		-0.5
D7	4	4	100.0		37.5	37.5	37.6	37.5	37.1	36.7		-0.8

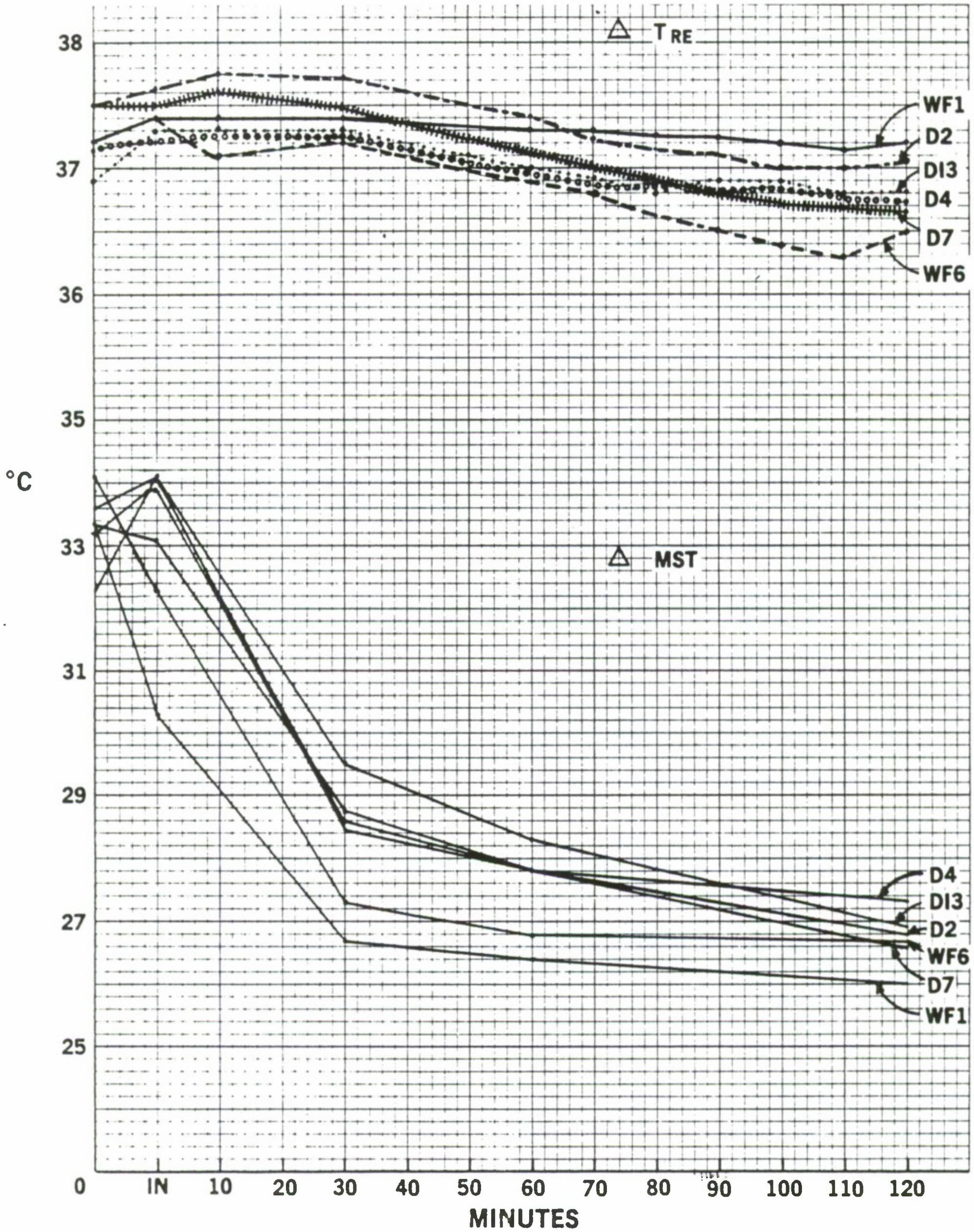

Figure 7. Δ T_{RE} and Δ MST (°C) for 120 Minute Runs in 0°C Water

Table XIX. MST (°C) for 120 Minute Runs in 0°C Water

	# OF 120 MIN. RUNS	TOTAL # OF RUNS	% OF 120 MIN. RUNS		PRE-TEST MST	WATER ENTRY	10 MIN. RAFT BOARDING	30 MIN.	60 MIN.	120 MIN.		△ MST
WF1	2	4	50.0		33.3	30.3	26.4	26.7	26.4	26.0		-7.3
WF6	2	4	50.0		34.1	32.5	26.5	27.3	26.8	26.7		-7.4
D13	3	4	75.0		32.3	34.1	30.0	29.5	28.3	26.9		-5.4
D2	4	4	100.0		33.2	33.9	29.4	28.7	27.8	26.8		-6.4
D4	4	4	100.0		33.3	33.1	28.9	28.7	27.8	27.3		-6.0
D7	4	4	100.0		33.6	34.0	30.1	28.6	27.8	26.6		-7.0

No conclusive statements can be made concerning the Summer Flying Coverall (W1) since all runs in 7.2°C water were terminated in 60 minutes or less. Rectal temperature changes (T_{RE}) for exposures this short in duration are difficult to interpret since the body's reaction time for core temperature lags somewhat. Mean skin temperature (MST) data is also limited by the early termination of the runs. However, it is of interest that the levels of MST while wearing W1 reached approximately 18°C or lower after only 30 minutes of exposure. For all other configurations tested, MST was approximately 18°C or higher after 120 minutes of exposure. The rapid drop in MST while wearing W1 would result in extremely low subjective tolerance and acceptance levels for this configuration.

FIRE PROTECTION ANALYSIS

Note: Only those configurations which were included in the immersion hypothermia test phase were analyzed for fire protection.

It is expected that all of the configurations tested in 7.2°C water will offer at least the minimal level of fire protection required for aircrewmen provided they are worn with the proper under- and over-garments as specified for use in this test program. These over- and under-garments include any underwear specified as well as the use of the CWU-27/P high temperature resistant aramid flight coverall when required. The CWU-27/P coverall is required as part of the configuration for WF2, WF3, D1, D2, D4, D7 and D8. The other four configurations, WF6, D13, D6 and W1, which is the CWU-27/P coverall, are expected to offer sufficient fire protection without an additional high temperature resistant aramid coverall. These four configurations will be discussed first.

(W1) CWU-27/P Summer Flying Coverall

This configuration is the standard issue coverall for Naval as well as Air Force aircrewmen and, for purposes of this test program, was worn with one set of high temperature resistant aramid thermal underwear. Fire pit testing of this coverall for a 3-second exposure to an Av Gas fire was previously conducted (reference 10) with the following results. Severe burns were indicated on 70.5 percent of the body surface with the suit burning through in many areas. Since these tests were conducted with summer weight cotton underwear under the flight coverall, the ignition of the underwear in areas where the suit burned through was considered to contribute greatly to the burn effect. By contrast, this test configuration utilizes full length high temperature resistant aramid thermal underwear which would not support flame should the coverall itself burn through. The full body coverage of the underwear would be expected to decrease the percentage of severe burns observed. This expectation can be supported by data of previous tests (reference 10) which compared single and double-layer high temperature resistant aramid gloves for hand protection. The single layer gloves shrank and burned through similar to the coverall and severe burns were indicated on the back of the hands. By contrast, the double layer gloves fully protected the hands. Although the outside layer was scorched and burned through in some areas, the inside layer was completely intact. Similar results could be expected by the additional aramid layer of protection offered by the thermal underwear. Any additional flight gear worn would provide extra layers of thermal protection to the body. The only potential hazard lies with additional flight gear fabricated of nylon. Since nylon supports flame and melts when exposed to fire, the possibility of bare skin contact with molten nylon would exist.

(WF6) CWU-33A/P Anti-Exposure Flying Coverall

As indicated by previous studies (reference 11) the innershell of the CWU-33/P Anti-Exposure Assembly did not support flame or burn through when passed through the flames of an Av Gas fire in a 25-foot path for 3 seconds. In addition, all areas of the test manikin covered by the innershell were fully protected by the suit from burns, even though the outer surface of the suit charred and cracked. The CWU-33A/P Coverall is identical to the CWU-33/P Innershell except the neoprene sleeves are cut off just above the elbow, with high temperature resistant aramid sleeve extensions added to protect the lower arms. In addition, one set of high temperature resistant aramid thermal underwear is to be worn under the suit and would therefore add an extra layer of thermal protection for the lower arms should the sleeve extensions burn through.

(D6) NADC Experimental "Goretex" Coverall (Twill Weave)

This configuration is fabricated of 6.5 oz/yd^2 high temperature resistant aramid fabric bonded to polytetrafluoroethylene film ("Goretex") which does not support flame. Should this coverall burn through during exposure to flame, the wearer will have on two sets of high temperature resistant aramid thermal underwear which will not support flame and would be expected to offer additional and sufficient thermal protection.

(D13) ILC AE-2 Anti-Exposure Coverall

This prototype configuration is fabricated of three layers consisting of (1) an inflated bladder system; (2) a nylon laminated to "Goretex" shell; and (3) a high temperature resistant aramid coverall. It is also worn with one set of aramid thermal underwear. The underwear and the coverall are expected to offer sufficient fire protection; however, a potential hazard lies with the nylon/"Goretex" layer. Although the "Goretex" is nonflammable, the nylon will support flame and melt. On production garments, this danger could be averted by laminating the "Goretex" to a light weight aramid fabric instead of the nylon.

The following discussions address the configurations which require the wearing of the CWU-27/P high temperature resistant aramid coverall.

(WF1) Mustang UVic Flight Jacket

This configuration requires that one set of high temperature resistant aramid thermal underwear as well as the CWU-27/P coverall be worn under the jacket. Although the outershell of this commercially available version is fabricated of nylon, high temperature resistant aramid fabric could be substituted in items purchased for military use. This, in combination with the other aramid layers, would be expected to offer sufficient protection.

(WF3) Surfer Shorty Suit

This configuration will provide 1/8-inch thick neoprene foam over the torso, upper arms, and upper legs thereby protecting these areas in a way similar to that cited in reference 11, already discussed. The remaining areas of the body are expected to be sufficiently protected by the single set of aramid thermal underwear and the CWU-27/P coverall.

Configurations D1, D2, D4, D7 and D8 are alike in that they are all fabricated of flammable materials. To offer sufficient protection against fire, all of them are required to be worn with an outer CWU-27/P coverall. This coverall will serve the additional purpose of protecting these suits from some of the daily wear that they would otherwise be exposed to. In addition to the coverall, configurations D1 and D7 are required to be worn with one set of aramid thermal underwear along with their own special underwear. Configurations D2, D4, and D8 are required to be worn with two sets of thermal underwear, since no special undergarments are designed specifically for use with them. These layers of underwear, in addition to the CWU-27/P coverall, are expected to offer sufficient thermal protection should the wearer be exposed to fire in any of these configurations.

RELIABILITY AND MAINTAINABILITY ANALYSIS

This discussion addresses only those configurations tested in 7.2°C water.

RELIABILITY OF DRY SUITS

The reliability of all "dry" suits is dependent on maintaining the integrity of the suit in order to assure "dryness" of the wearer. The degree to which this integrity is compromised, and the number and quality of undergarments worn, will determine the extent to which protection is decreased. All of the "dry" configurations tested in 7.2°C water are fabricated of breathable waterproof materials. Three of the configurations, D1, D6 and D13, are fabricated with a single water impermeable layer while the other four, D2, D4, D7 and D8 are fabricated with two water impermeable layers. Considering this design feature alone, the two-layer suits would be expected to have a somewhat higher reliability since there are certain types of damage which might effect only one of the layers and not necessarily negate protection as extensively as if these same damages should occur on the single layer of D1, D6 or D13. Tears, pin holes, and the deposit of body oils are among the potential damages which conceivably might occur to only one of the two protective layers. Other damages, including oil stains or improper laundering and/or care would most likely effect both layers of a two layer suit, and in the presence of these damages, the two layer garments would not be expected to be any more reliable than the single layer garments.

To maintain integrity, all dry suits require some form of seals and/or socks to prevent water entry at the extremities and neck. To meet this requirement, all of the designs tested included some form of neck seals, wrist seals and socks except D8 which was designed with ankle seals in lieu of socks. Damage to any of these critical parts will compromise protection to the extent of the severity of the damage. Neck and wrist seals on suit D1 are fabricated with 13 oz/yd^2 thin, coated, stretch fabric and D2 and D4 seals are fabricated of thin, highly stretchable rubber. The neck seals on these two suits are convoluted. D8 and D6 utilize a slightly heavier 19 oz/yd^2 coated stretch fabric and D7 utilizes 1/8 inch thick neoprene foam for the seals. D13 is unique in both design and materials since it includes an inflatable bladder, inside the water impermeable layer, for thermal protection. This bladder includes inflatable neck and wrist seals. Concerning reliability of these various approaches, experience by the U.S. Navy with D1 has shown its neck and wrist seals to tear quite easily and frequently. Likewise, testing by the Australian RAF has shown that D2 is also prone to tearing after very minimal use. Since the seals on D4 are essentially the same material and design as D2, frequent tearing for this configuration would also be expected. In contrast, suits D6 and D8 would be expected to tear much less easily due to the increased weight of the material used. The seals of suit D7 would be expected to be the most tear resistant. D13 would not be prone to tearing since the snug fit of the seals is achieved only after inflation of the suit. However, the function of the seals would be totally negated by a puncture anywhere in the bladder layer of the garment.

By the way of design differences, suits D7, D8 and D13 are designed with the main closure slide fastener going through the neck seal while D1, D2, D4 and D6 are of a "pull-over" design. Although having the slide fastener go through the neck seal reduces the stress on the seal material during the donning and doffing sequences, the danger of the neck seal being left open at the time of immersion is greatly increased. Should this occur, the neck seal would be nonfunctional and the suit would rapidly fill with water, virtually negating its exposure protection. Likewise, should D13 be entered into the water uninflated, no restriction of water flow into the suit would occur.

For the feature of sock vs. ankle seal, the socks are considered to be more reliable from a leakage standpoint than the ankle seals. This is due to the fact that the feet normally remain immersed in the water for a longer period of time and ankle seals are more prone to leak than a closed sock design.

In the design and fabrication of the socks, D1 and D6 use a molded cotton flocked rubber stretch material which, from experience, is very prone to tears. D7 uses molded, flocked rubber socks only slightly heavier than those used on D1 and D6. D2 uses double textured nylon butyl fabric which is seamed and taped. D13 uses a nylon/"Goretex" laminate with coated seams. D4 uses a heavy weight molded rubber sock. Of these, D2 is considered to offer the best compromise for reliability and comfort.

All of the "dry" suits utilize at least one water-proof slide fastener or closure. D13 uses an extruded plastic closure for water-proof sealing which is different than all of the other configurations which use a standard rubber sealing type of slide fastener. Suits D1, D2, D4, and D6 use a second relief portal slide fastener. All of the suits could potentially experience damage to these slide fasteners either in the form of obvious inoperability or in more subtle, less detectable, loss of sealing capability. If uncorrected, the loss of sealing capability could result in varying amounts of water leakage depending on the severity of the damage. Furthermore, during donning, the wearer must assure that a firm closure is made so that no leakage occurs. Suits D7, D8 and D13, as mentioned previously, are designed with the slide fastener passing through the neck seal so that complete closure is critical for the neck seal to function properly. The suits with only one slide fastener are expected to be more reliable than those with two slide fasteners simply by the reduction of the number of potential failure points.

There are also usage requirements for these "dry" suits which are generally unrelated to the variations in individual designs. These include the requirement for the proper fitting of neck, wrist, and ankle seals and/or socks; the wearing of the proper undergarments; and assuring that skin contact with all seals occurs at the time of donning. The lack of proper performance of any of these requirements will result in varying degrees of protection loss depending on how poorly these requirements are met. In addition to these, D13 requires the user to inflate the inner bladder prior to water entry in order for the suit to function properly. Without inflation, this suit will rapidly fill with water due to lack of functioning wrist and neck seals.

In summary, each dry suit tested has some individual features which could potentially decrease its reliability while in use by the Fleet. The importance of each of these features on the actual inservice reliability of the suits is difficult to assess, but suits with more of these "weak" design features would be expected to be generally less reliable. Table XX identifies each suit and the areas which would be expected to have a negative effect on reliability. In addition to these, all of the dry suits will depend on the proper fit and wearing of seals and the proper closure of slide fasteners in order to assure integrity and ultimately reliability. From table XX, it is obvious that none of the suits tested are completely optimum in design, from a reliability viewpoint. The best design features for a dry suit are considered to be the following:

(1) If possible, the use of two water impermeable layers is preferable. The possible exception to this requirement would be if the "Goretex" laminate layers, such as used on D6 and D13 can be shown to be less sensitive to the rigors of daily wear than the woven "Ventile" fabrics have proven to be. Since "Goretex" is a fairly recent development in the field of immersion hypothermia protection, it is net yet known how it will perform when faced with the effects of daily wear.

(2) A pull-over neck seal design is preferable to a slide fastener through the seal, in order to avoid the potential impact of the wearer flying with the slide fastener open and neglecting to close the seal prior to water entry. The choice of a pull over seal requires the use of a reasonably elastic material with good recovery characteristics and tear resistance. The materials used on D6 and D8 appear to be reasonably good material choices for this feature.

Table XX. Identification of the Potentially Weak Design Features of Dry Suits

Potentially Weak Areas of Design	D1	D2	D4	D6	D7	D8	DI3
Only One Water Impermeable Layer	X			X			X
Easily Torn Wrist and Neck Seals	X	X	X				
Easily Torn Socks or Ankle Seals in Lieu of Socks	X			X	X	X	
Two Slide Fasteners	X	X	X	X			
Slide Fastener Through Neck Seal					X	X	X
Inflatable Neck and Wrist Seals*							X

*This may or may not be considered a weak feature. There are several advantages to this approach.

(3) Socks are preferable to ankle seals, and again a material soft enough for comfort yet reasonably tear-resistant is required. The design and material of D2 appears to be a good choice and that of DI3 may be a reasonable alternative.

(4) Wrist seals do not require as much stretch and recovery as neck seals so the use of a highly tear resistant material is possible. The choice of D7 appears to be the best material of the types studied. A special comment is in order here regarding the design of suit D3. Although this suit was not tested in 7.2°C water, its wrist seal design is unique and warrants consideration. The key feature of the wrist seal is that it is designed with the cotton ventile layer of the coverall extending down to the wrist, over the wrist seal. This helps to reduce the amount of direct water flow against the cut edge of the wrist seal and decrease the chances of even slight leakage at this point.

(5) The use of water-proof slide fasteners is inevitable but using only one, for both donning and as a relief portal, is preferable to two separate slide fasteners. This will require an essentially vertical orientation of the slide fastener, offset at the neck area to avoid going through the neck seal.

The inflatable bladder approach of DI3 may, with further investigation, prove to be a reliable one. The primary problem of this approach is the requirement for the user to be aware enough to inflate the suit prior to water entry. Otherwise, the suit's reliability is totally negated. Since the current policy in the design of new equipment is to decrease, where possible, the actions required by the user, it does not appear that this approach is acceptable unless the other advantages of the suit, such as comfort and protection, outweight this disadvantage.

RELIABILITY OF WET SUITS

In general, wet suits are expected to be more reliable than "dry" suits since minor damages normally will not seriously negate their thermal protection. The protection of wet suits is afforded by allowing a controlled thin layer of water to flow into the suit upon water immersion. This thin layer of water is warmed by contact with the wearer's body. The neoprene foam of the suit provides an insulating layer which prevents the wearer's body warmth from being lost to the colder water outside the suit. Protection increases as the thickness of the foam is increased. The critical factor for the successful performance of a wet suit is fit. If too much slack is allowed, excessive water will flow into the suit resulting in an inability of the wearer to warm the water. If snugness of fit is not attained at the suit endings, the control of water flow in and out of the suit will not occur and a continuous influx of water can result.

In evaluating the wet suits tested in 7.2°C water, two of them, WF3 and WF6, are "true" wet suits. WF6 provides wet suit coverage of the torso, legs to the ankle, and arms to just above the elbow. WF3 provides wet suit coverage of the torso, the legs to mid-thigh and the arm to mid-biceps. Both are fabricated of 1/8 inch thick neoprene foam.

WF1 is a jacket configuration which is designed to provide protection for the torso and arms and which could be classified as a "pseudo" wet suit since it doesn't operate precisely like a wet suit as just previously defined. Closed cell ensolite foam throughout the jacket provides thermal protection. A beaver tail and neck flap constructed of 1/8 inch thick neoprene foam protect the vital groin and upper body areas. The deployment of the beaver tail restricts water flow into the jacket.

With the exception of an inoperable closure zipper or extensive tears in the foam layer, there are no other types of damage which would result in any substantial loss of hypothermia protection.

Since inoperability of the slide fastener and/or large tears in the foam would very rarely go undetected, these suits would not be expected to perform unreliably as a result of daily wear.

Usage requirements for these wet suits include (1) the selection of the proper size and custom fit when necessary and (2) the wearing of proper undergarments. As mentioned previously, size selection is probably the most critical factor affecting wet suit reliability. For WF1 and WF3, wearing of the proper undergarments is also critical since portions of the extremities are not protected by neoprene foam. In addition to these, WF1 has the unique requirement that the beaver tail be deployed and cinched up prior to water entry, if worn under garments which prevent deployment after their donning. Without this action, the protection of this suit is seriously degraded.

To summarize, suits WF3 and WF6 would generally be expected to be slightly more reliable than WF1 only in the fact that they don't require a specific action by the wearer prior to water entry. All of these suits would be expected to be more reliable than the dry suits. The key factor in selection of a wet suit should be that an adequate and proper size range is provided to outfit the fleet. Currently, WF1 is available in 8 sizes – 4 for men and 4 for women. WF3 is available in 12 sizes – 6 for men and 6 for women. WF6 is available in 20 sizes for men.

MAINTAINABILITY

Maintainability is based on the probability that an item will be retained in or restored to an operable condition within a given period of time. Two categories of maintenance contribute to maintainability. Preventive maintenance is the actions performed in an attempt to retain an item in an operable condition by providing systematic inspection, detection and prevention of failure. Corrective maintenance is the actions performed to restore the item to an operable condition once a failure has occurred or a defect has been identified.

One general difference between "wet" suits and "dry" suits is the effectiveness of preventive maintenance actions. The dry suits tested in 7.2°C water are all fabricated of breathable fabrics which become water impermeable when immersed. Cotton ventile fabrics, and to a lesser extent "Goretex" laminates, are susceptible to damage which is not always easily detected by visual inspection, yet, can have a major impact on the protection afforded by the suit. This fact decreases maintainability by making it difficult to retain these suits in an operable condition by way of preventive maintenance. In contrast, damage to the material of wet suits is generally obvious and easily detected.

In addition to the basic material, dry suits also have many other potential failure points which are not always detected by visual inspection. Examples include leaking seams or slide fasteners and improperly fitted wrist and neck seals. Since wet suits are generally simpler in design and do not rely on water-tight integrity for successful operation, visual inspections are usually successful in identifying critical damages.

Considering corrective maintenance, dry suits will require more down time for corrective maintenance due to the increased number of potential failure points which would necessitate repair or replacement. Corrective maintenance of wet suits is generally limited to repair of tears or holes in the basic material of the suit and to replacement of slide fasteners and seam tapes. In constast, dry suits may require patching of the basic material, repair of broken stiching, repair or replacement of seam tapes, and replacement of neck and wrist seals, socks, slide fasteners and any insert panels. The increased time required for corrective maintenance and the likelihood of damages beyond the authorized limits of repair would be expected to decrease the maintainability of dry suits.

In evaluating the differences among the dry suits tests, we see correlations between reliability and maintainability. Those suits with features that are more reliable incur less frequent failures and/or damage thereby increasing the success rate of preventive maintenance and decreasing the time required for, and extent of, corrective maintenance. We can therefore assume that the features already identified as important for increasing reliability should also be adopted for the sake of maintainability. A dry suit which is uniquely designed and therefore requires some additional discussion is the AE2 Anti-Exposure Coverall (D13). This configuration incorporates a "Goretex" laminate as a waterproof layer, but has the additional feature of an inflatable bladder throughout the suit which provides neck and wrist sealing as part of its design. With regard to maintainability, the inflatable bladder can be easily checked for damage by simply inflating it. Although the frequency of repair is not known, the difficulty of repair should be within the capability of organizational and intermediate levels. It is not expected to have a lower maintainability since frequent replacement of wrist and neck seals would be eliminated.

In summary, the wet suit approach to anti-exposure protection is considered to be more maintainable than the dry suit approach. Among the wet suits tested in 7.2°C water, suits WF3 and WF6 would be expected to be somewhat more maintainable than WF1 by virtue of the simplicity of their design. Among the dry suits tested, the two-layer ventile suits (D2, D4, D7, and D8) would be slightly more maintainable than the single layer ventile suit (D1), since the suit would be retained in an operable condition even if minor damage to one of the layers should go undetected. Furthermore, suits D7 and D8 have more durable wrist and neck seals than D2 and D4 which would result in less frequent repair or replacement and thereby decrease corrective maintenance time. The two "Goretex" suits (D6 and D13) are expected to be somewhat more maintainable than the ventile suits since the susceptibility of "Goretex" laminates to undetected damages is expected to be less.

LOGISTIC SUPPORTABILITY ANALYSIS

Logistics is generally accepted as a support function — a secondary role to the hardware role in accomplishing a mission. However, no mission can be successfully accomplished or sustained, without adequate and timely logistics. It is therefore important to identify any anticipated logistics problems which are evident for the test configurations as well as the extent of logistics activities required prior to fleet introduction.

DOD Directive 4100.35 (1 October 1970) and its Navy implementing issuances identify the following nine principal elements of logistic support:

- Supply Support (SS): Those activities and efforts planned and performed to cause timely provisioning, distribution and inventory replenishment of spares, repair parts, supplies, and repair of repairables for a predetermined state of supply readiness
- Facilities (FAC): The planning activities undertaken to assure that all required facilities are available to operating forces and supporting activities in a timely manner
- Support and Test Equipment (SE): Those equipments identified as necessary to support and test operational capabilities and availability of system/equipment for operating forces and supporting maintenance activities
- Personnel and Training (PT): The program defining requirements for trained operations and maintenance personnel, the need for training devices to support instruction or simulated settings, and the generation of specific manning plans and requirements
- Technical Data (TD): The recordable information required of, and generated by, the planning and performance cycles. Those data, of chiefly engineering import, that have to be managed from generation through verification
- Transportation and Handling (TH): The functional requirements and actions necessary to ensure the capability to transport, preserve, package and handle all equipment and support items
- The Maintenance Plan (MP): The documentation of concepts and requirements for each level of equipment maintenance to be performed during its useful life
- Logistic Support Management Information (LSMI): The recordable information required to support information and contract systems to meet technical and support management needs; chiefly those data that aid in managing a weapon system
- Logistic Support Resource Funds (LSRF): The program of activities that determines and justifies logistic support funding needs, monitors funds expenditures, updates funding requirements, and forecasts prospective funding needs for timely fiscal planning

The first element, Supply Support (SS) is perhaps the most critical, since timely provisioning of sufficient quantities of the selected configuration and its required repair parts directly impacts the ability of the Fleet to perform its missions. There are several factors which effect Supply Support. First of all, the source of the selected configuration will effect how easily and quickly quantities can be procured. The suits tested fall into the following categories regarding source:

Domestic military	WF6, D1, D6[a]
Foreign military	WF1[b], D2, D4, D7, D8
Domestic Commercial	WF2, WF3, D13[a]
Foreign commercial [c]	WF1[b], D2, D7, D8

a. Prototype configurations, not available off-the-shelf or to a specification

b. Military version of WF2

c. Military configurations available from a single commercial source in their country of origin.

Procurement from foreign sources presents several problems for supply. First, foreign procurements must be well justified and the inability to obtain an equivalent item from domestic sources must be well documented since such procurements are in opposition to the "Buy American Act." Secondly, permanent dependence on a foreign source for replenishable military goods is not desirable. In the event of a shortage of garments, the foreign government's military requirements would most likely take precedence over those of the United States. The problem with all of the foreign dry suit (D) configurations is that the basic material from which they are fabricated is not available in the United States. This would result in a dependence on foreign sources for materials even if domestic manufacturers of the garments themselves were identified. The problems resulting from such dependence have been well documented by the USN and USAF efforts to obtain cotton ventile fabric in sufficient quantities to fabricate CWU-21/P coveralls (D1) for the two services. Shortages of these garments have been evident since Navy adoption in 1978, and it appears that shortages will continue to exist with no relief in sight. The inability to guarantee sufficient and timely provisioning of suits, fabricated from these materials, is unacceptable.

The timely provisioning of repair parts becomes more difficult as the types and sizes of repair parts required to support a configuration increases. Table XXI summarizes the types of repair parts required for each configuration, the extent to which each of them is sized and whether or not emergency Fleet fabrication would be possible. As indicated in Table XXI, the dry suits (D) in general, have more extensive requirements for repair parts than the wet suits (WF). Among the dry suits, suits D2 and D4 may be easier to supply with repair parts since the wrist and neck seals are only available in one size and the replacement of slide fasteners is not authorized according to their current maintenance manuals. Suit D13 may also be more easily supported since there are no separate wrist and neck seals at all. Among the wet suits, WF6 requires slightly more repair part support than the other suits (WF1, WF2, WF3).

Although not directly related to Supply Support, the cost of the configurations does have some limited impact on the selection process. The following prices are approximate in the case of prototypes, or are the prices charged by the manufacturer as of January 1979.

Table XXI – Repair Part Requirement

		WF1 *	WF2 *	WF3 *	WF6 *	D1 *	D2 *	D4 *	D6 *	D7 **	D8 *	DI3 *
Neck Seals	Required?					X	X	X	X	X	X	
	Number of Sizes?					4	1	1	4	1	?	
	Fleet Fabrication Possible?					X			X	X	X	
Wrist Seals	Required?					X	X	X	X	X	X	
	Number of Sizes?					4	1	1	4	3	?	
	Fleet Fabrication Possible?					X			X	X	X	
Socks	Required?					X	X	X	X	X		X
	Number of Sizes?					8	9	8	8	9		?
	Fleet Fabrication Possible?						X					X
Ankle Seals	Required?										X	
	Number of Sizes?										?	
	Fleet Fabrication Poss?										X	
Slide Fasteners	Closure – # of Sizes	Max. 6	Max. 12	Max. 12	Max. 20	4	Not Auth.	Not Auth.	4	1	Max. 5	?
	Relief Portal					1	Not Auth.	Not Auth.	1			
	Leg				1							
	Basic Suit Fabric (S)	X	X	X	X	X	X	X	X	X	X	X
	Seam Tapes				X	X	X	X	X	X	X	?
	Stretch Fabric (Insert Panels)					X			X			

* Based on info. in available maintenance manual
** Based on maintenance manual for D1 since design of suit is same
* No maint. manual available

WF1	$78.00
WF2	$152.00 (australian dollars)
WF3	$63.50
WF6	$192.00
D1	$270.00 (includes CWU-23/P liner and 1 pr. of SRU-25/P socks)
D2	$528.45 (includes socks)
D4	$587.50 (includes socks)
D6	$175.00 (estimate)
D7	$340.00 (includes socks)
D8	$538.00 (includes ankle seals)
DI 3	$350.00 (estimate)

In general, the cost of "dry" suit configurations is higher than that of "wet" suit configurations. This, coupled with more extensive repair part requirements, results in the "dry" suits being more expensive to support.

The next two elements, Facilities (FAC) and Support and Test Equipment (SE), effect how easily a given configuration can be introduced to and supported by the Fleet. No peculiar ground support equipment (GSE) or facilities are required for the "wet" suit configurations (WF1, WF2, WF3, and WF6). These suits can all be supported with common hand tools and facilities. In contrast, the "dry" configurations require various types and sizes of special forms or cylinders for attachment of seals and/or socks, as applicable. In addition, special laundering or treatment facilities would be required. Due to the difficulty in assessing the water-tight integrity of these suits by visual inspection alone, many of the maintenance manuals for the "dry" suits require a periodic full immersion of the suit in water while being worn. This would require the availability of a water tank or similar facility. The suits which currently prescribe a full immersion leakage test are D2, D4 and D8. D13 would also require an inflation test apparatus to check the integrity of the inflatable bladder.

Considering the element of Personnel and Training (PT), all of the configurations except WF3 and WF6 require some special user training, albeit minimal in some instances. In addition, all of the "dry" configurations require special maintenance training due to the special care requirements for the basic suit materials and the criticality of inspection procedures. WF3 and WF6 would require special training in customizing the fit of these suits.

The element of Technical Data (TD) encompasses many records which extend past the point of Fleet introduction, but for purposes of this analysis only those items important for initial procurement and production will be considered. In this regard, the way in which each configuration can be identified for procurement purposes varies. Table XXII summarizes the status of each configuration in terms of how the configuration baseline is identified; i.e., by specification, part number, etc.

In addition to procurement information, certain documents are required for obtaining Navy Approval for Service Use (ASU). These include a Test and Evaluation Plan (TEP/TEMP), Reliability and Maintainability Verification, a System Safety Plan (SSP), an Integrated Logistic Support Plan (ILSP), a Maintenance Plan (MP), and fleet verified technical manuals. With the exception of D1 and WF6, all of these data items would have to be prepared prior to ASU of any of the test configurations.

For the element of Transportation and Handling (TH), all configurations can be packaged and transported by normal methods. However, those configurations fabricated of ventile material (D1, D2, D4, D7, and D8), and to a lesser extent those configurations fabricated of "Goretex"

Table XXII — Procurement Data Status

	WF1	WF2	WF3	WF6	D1	D2	D4	D6	D7	D8	DI3
U.S. Military Specification Available				X	X						
Foreign Military Specification Available		X				?	?		?	?	
Commercially Part-Numbered	X	X	X			X			X	X	X
Available "Off-the-Shelf"	X		X								
NATO Stock Numbers Available		X		X	X		X		X		
Prototype								X			X

laminates (D6, DI 3), will require special care in handling and storage. In addition, the daily care and storage of these configurations, by the user, is somewhat critical if damage is to be prevented. These configurations must be handled and stored in such a way as to prevent contact with oils, acid, high humidity, extremes of temperature, or with other equipments which may abrade or tear the suit materials. Daily care also requires periodic cleaning and /or treatment which differs from the conventional squadron laundering capabilities.

The next element listed is the Maintenance Plan (MP). Although only one configuration, D1, has an approved Navy Maintenance Plan, five of the configurations (WF6, D1, D2, D4 and D7) have maintenance manuals available. These manuals could be fleet verified and a Navy Maintenance Plan could be generated based on the information contained within them. The remaining configurations (WF1, WF2, WF3, D6, D8, and DI 3) would require development of both a maintenance plan and a maintenance manual prior to Fleet introduction.

The last two elements, Logistic Support Management Information (LSMI) and Logistic Support Resource Funds (LSRF) are the elements which deal with carrying out the Integrated Logistic Support process and activities. These elements would have to be identified for all of the configurations except WF6 and D1 since these two are already in the U.S. inventory and are being logistically supported.

Summary: Table XXIII provides a summary of the logistic support elements for the test configurations. In general, the "wet" suits are expected to be more logistically supportable than the "dry" suits. This is due to several features including:

(1) guaranteed material availability

(2) generally lower cost per configuration than "dry" suits

(3) fewer repair part requirements

(4) supportability with common equipments and facilities.

(5) no special handling or transportation requirements

(6) all immediately available for procurement

(7) no requirement for both special user and maintenance training.

Of the four "wet" suit configurations, the most difficult to support would be WF2 since it is available from a foreign source.

The "dry" suits are expected to be generally more difficult to support due to:

(1) availability of sufficient material not being assured (exceptions to this are D6 and DI 3)

(2) availability of material and/or garments from foreign sources only (exceptions are D6 and DI 3)

(3) greater number of repair part requirements

(4) generally higher cost per configuration than "wet" suits

(5) requirements for special tools and facilities

(6) both special user and maintenance training required

(7) special handling and storage requirements

The most critical limitation to most of the "dry" suits is the inability to assure sufficient quantities of material for timely provisioning of suits to the Fleet. No configuration which cannot be provided in sufficient quantities can be considered acceptable. The only two "dry" configurations which do not pose this problem are D6 and DI 3. Although currently both prototypes, they must still be considered the best "dry" configurations in terms of supportability.

OPTIMAL TECHNOLOGY SELECTION AND MISSION SPECIFIC RECOMMENDATIONS

DISCUSSION:

This evaluation program has attempted to assess a variety of anti-exposure technologies under the guidelines of the current U.S. Navy Operational Requirement for Cold Water Exposure Protection. In reviewing the results of the various physiological test phases and analyses, it becomes evident that no single approach can be considered the best for all of the criteria evaluated. First, let's review the best and worst performers for each of the selection criteria.

For mobility, the best configurations were some of the commercial wet suits (WF3 and WF5), some of the two-layer "dry" suits (D2, D3, and D8), the Australian Jacket worn outside the torso harness (WF2 out), and the NADC "Goretex" Coverall (D6). The worst configurations were the Mustang UVic Jacket worn inside the torso harness (WF1 in), the ILC Tube Suit (W3), the Canadian Suit (D4), and the CWU-33A/P Coverall (WF6).

For heat stress, the best configurations were the breathable "dry" suits while the majority of the wet form (WF) suits performed considerably worse. The UVic Jacket worn outside the torso harness (WF1 out) fell between the rest of the wet foam suits and "dry" suits in performance.

For immersion hypothermia protection, all of the configurations tested, with the exception of the Summer Flying Coverall (W1), met the requirements of the Operational Requirement, but the two-layer "dry" suits (D2, D4, D7 and D8) exhibited lower leakage levels than the one layer "dry" suits. These same suits, along with the ILC AE2 Coverall (DI 3) maintained a higher level of mean skin temperature than the other suits tested.

For fire protection, all of the configurations evaluated in the immersion hypothermia phase will offer at least the minimal level of fire protection required provided they are worn with the proper under- and over-garments.

For reliability and maintainability, the "wet" suits offer many advantages over the "dry" suits due to their design simplicity. In the area of logistic supportability, the "wet" suits are also more favorable than the "dry" suits, and among the "dry" suits the domestic configurations (D6 and DI 3) are more desirable than the foreign configurations.

Table XXIII – Summary Of Logistic Support Elements Of The Test Configurations

		WF1	WF2	WF3	WF6	D1	D2	D4	D6	D7	D8	DI 3
SS	Assured Material Avail.	X	X	X	X				X			X
	Domestic Source – Material	X		X	X				X			X
	Domestic Source – Garment	X		X	X	X			X			X
	Number of Types of Repair Parts Required	2	2	2	4	8	5	5	8	6	6	4
	Cost Per Configuration $	78	152	64	192	270	528	588	175	340	538	350
FAC And SE	Supportable with Common Equip. and Fac.	X	X	X	X							
	Peculiar Equip. or Tools Required					X	X	X	X	X	X	X
	Special Facilities Required					X	X	X	X	X	X	X
DT	Special User Train. Reqd.	X	X			X	X	X	X	X	X	X
	Special Maint. Train. Reqd.			X	X	X	X	X	X	X	X	X
TD	Immediately Procurable To An Established Baseline	X	X	X	X	X	X	X		X	X	
TH	Special Handling And Storage Required					X	X	X	X	X	X	X
MP	Maint. Plan Available					X						
	Maint. Manual Avail.				X	X	X	X		X		

RECOMMENDATIONS

For use by Fighter/Attack, Fixed Wing, and Helicopter crewmen assigned to ejection and fixed seats, a two-layer "dry" suit appears to offer the best compromise for overall performance. Despite the generally negative aspects of "dry" suits with respect to reliability, maintainability and logistic supportability, this approach is far superior to the wet foam suits under conditions of heat stress. This type of garment will offer reasonable mobility, good performance under heat stress, and a more than adequate level of protection against immersion hypothermia. The selection of a two-layer approach is also expected to increase the reliability and maintainability of the configuration above the levels generally experienced with "dry" suits. The specific design features and material selections should include those already identified as important for increasing reliability and maintainability.

The basic material recommended for the body of the coverall is some type of "Goretex" film sandwiched between high temperature resistant aramid layers for fire protection. The selection of a "Goretex" laminate is based on its being available from a domestic source with no anticipated limitations on its producibility. Since the single layer "Goretex" Coverall (D6) performed at levels equal to or better than the single layer cotton ventile coverall (D1) throughout the test program, it is anticipated that a two-layer "Goretex" coverall will perform at levels equal to or better than the two-layer cotton ventile coveralls (D2, D4, D7, and D8). Preliminary mobility and heat stress testing seem to be confirming this expectation. The use of the "Goretex" laminates will also eliminate the need for wearing an additional outer fire resistant coverall, as is required for the two-layer ventile coveralls.

Other desirable design features for the recommended configuration include neoprene wrist and neck seals, similar in design to those used on the Danish Coverall (D7), a single vertically oriented closure slide fastener, socks similar in design and materials to those used on the British Coverall (D2), and a basic coverall design similar to the NADC "Goretex" Coverall (D6). The recommendation of a "zip-through" neck seal in lieu of a "pull-over" seal is made in the interest of improving user comfort while increasing the service life of the seal by the use of more durable materials. Also, the design of D7 is such that the slide fastener only extends halfway through the seal with an additional hook and pile closure strap securing the upper portion. Reasonable comfort during flight can be attained by closing the slide fastener entirely and leaving the closure strap unsecured. In this mode, water flow into the suit would be minimal if the closure strap were left open during water immersion.

For the use of mobile crewmen and passengers, a jacket design similar to WF1 and WF2 is recommended. Since these personnel are not required to wear either a torso harness or anti-g garment, the levels of performance for mobility and heat stress will most likely be better than those measured during the test program. Heat stress performance could further be improved by wearing the jacket partially unzipped for additional ventilation. Even if water immersion should occur while the jacket is open, or if the beaver tail is not deployed, these actions can still be taken after water entry with little protection loss. Due to its anticipated high levels of reliability and maintainability, the jacket should be able to withstand the rigorous daily environment of the mobile crewman better than any of the "dry" configurations. A small number of sizes (perhaps as few as four) could accommodate all passengers, and a jacket could be easily donned at the time of helicopter boarding. The jacket could also be designed for provision of an integrated life preserver and possibly stowage of some survival items and/or a personal one-man raft. The jacket outershell should be fabricated of high temperature resistant aramid fabric.

These recommendations apply to both the first and second stage levels of protection as delineated by the Operational Requirement. The only difference is that the recommended configuration alone can provide sufficient protection in 7.2°C water (first stage) while a flotation platform is required to assure meeting the operational requirement for 0°C water (second stage).

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HM2 M.K. Ammerman
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TD3 T.D. Neary
AMS3 M.G. Marzella
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WF2 UVic Flight Jacket (Protector Safety Products, Fawkner, Vic. Melbourne, Australia)

DI 3 ILC AE2 Anti-Exposure Coverall (ILC Dover, Frederica, Delaware)

D4 Canadian MK-1 Constant Wear Immersion Suit (Canadian Forces)

D7 Danish Flyer's Anti-Exposure Coverall (A/S Musk Ox, Naestved, Denmark)

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APPENDIX A

ANTHROPOMETRY MEASUREMENT PROCEDURES

ANATOMICAL LANDMARKS: Mark the following anatomical landmarks on each subject as reference points. (See Figures)

1. Anterior Scye Point Landmark: Place a horizontal straight edge as high as possible into the axilla without compression of the soft tissue; mark the skinfold on the front of the body at this level.

2. Biceps Landmark: Point of maximum protuberance on the front of the arm when the biceps muscle is contracted.

3. Medial Side of the Wrist Landmark: On the little finger side of the arm, feel for the most distal point of the wrist bone; mark this same level on the thumb side of the wrist.

4. Midshoulder Landmark: Midway between the side of the neck and the lateral edge of the scapula (shoulder blade).

5. Proximal to the Stylion Landmark: Just above the bony protuberances of the wrist.

6. Waist Landmark: Center of the navel.

7. NOTE: The Frankfort Plane is the standard horizontal plane or orientation of the head. The plane is established by a line passing through the right tragion (approximate earhole) and the lowest point of the right orbit (eye socket).

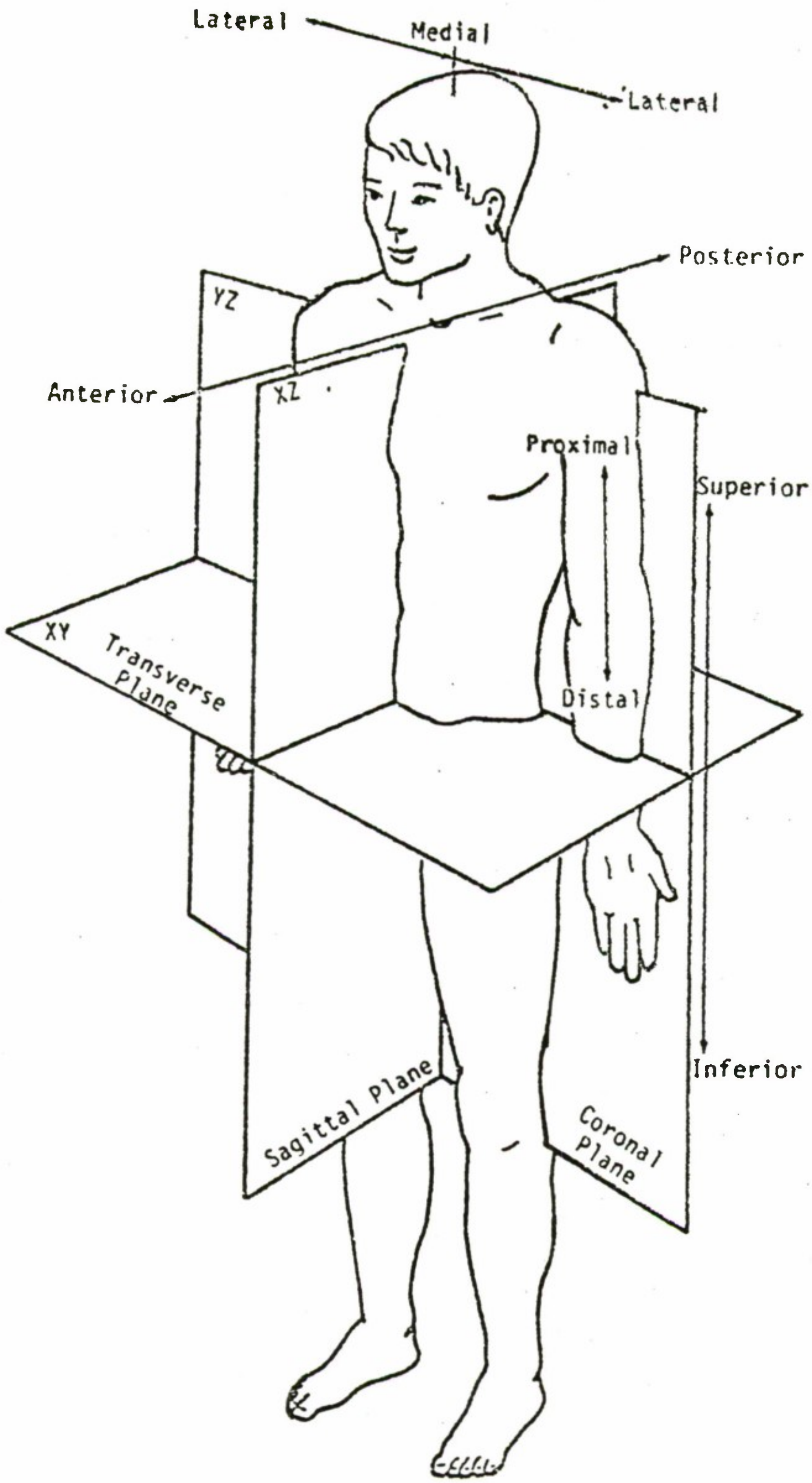


Figure A-1. Anatomical Planes and Orientations

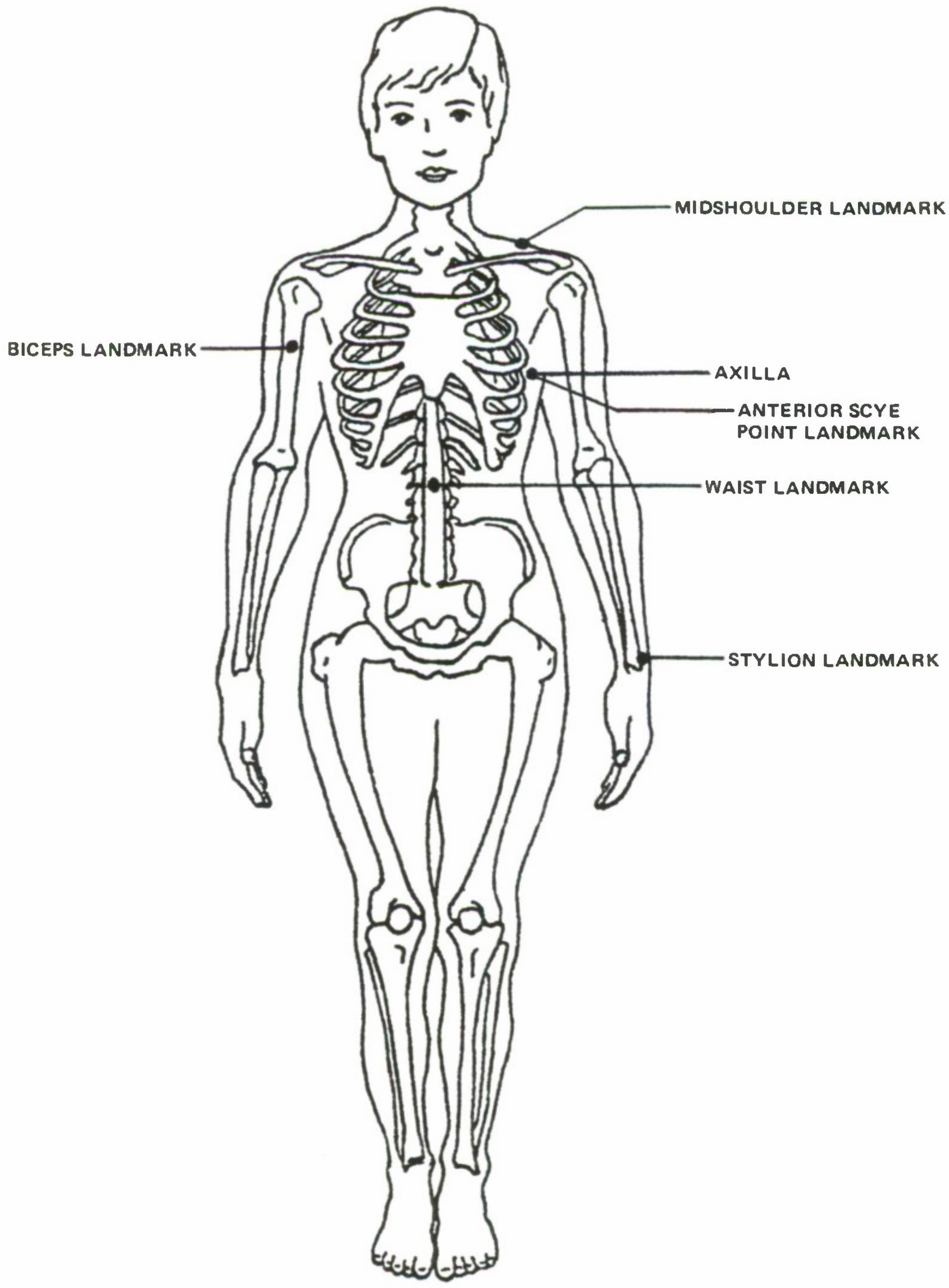


Figure A-2. Anatomical and Anthropometric Landmarks

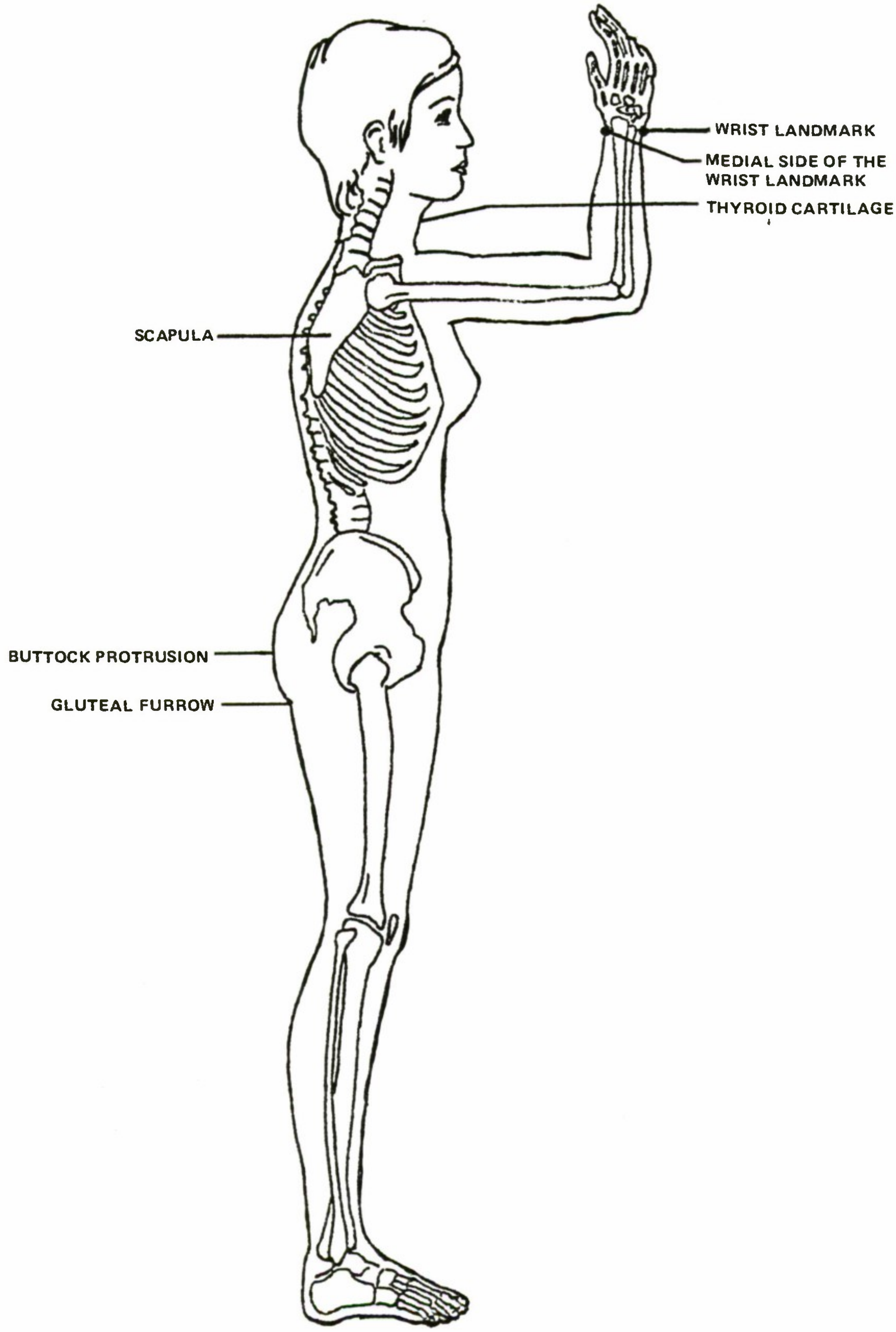
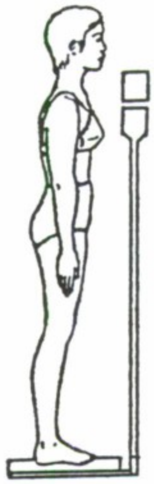
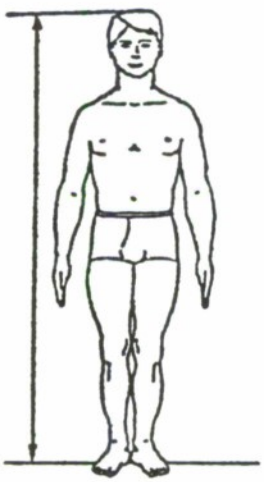


Figure A-3. Anatomical and Anthropometric Landmarks



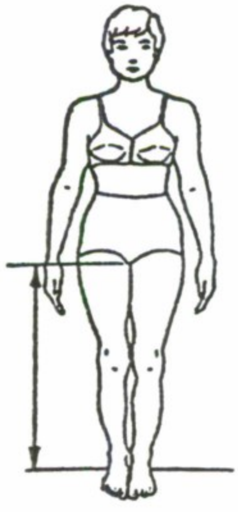
WEIGHT

Nude body weight as measured on physician's scales.



STATURE

The vertical distance from the standing surface to the top of the head. The subject stands erect, head in the Frankfort Plane, heels together, and weight distributed equally on both feet.

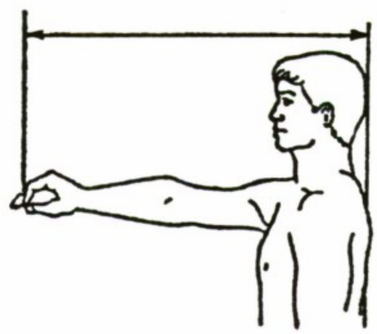


CROTCH HEIGHT

The vertical distance from the standing surface up into the crotch until light contact is made. The subject stands erect, heels approximately 10 cm. apart, and weight distributed equally on both feet.

SITTING HEIGHT

The vertical distance from tha sitting surface to tha top of the head. The subject sits erect, haad in the Frenkfort Plane, upper arms hanging relaxed. Forearms and hands axtanded forward horizontally.

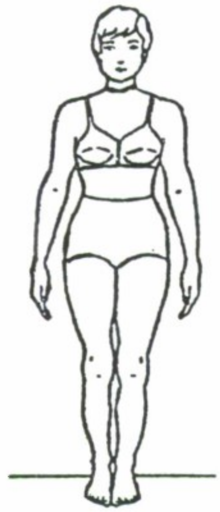


FUNCTIONAL (THUMB-TIP) REACH

Tha horizontal distance from the wall to the tip of the thumb, measured with the subject's back against the well, his arm extended forward horizontelly, and his index finger touching the tip of his thumb.

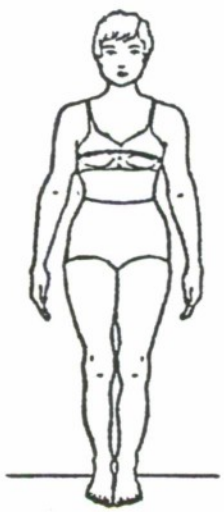
SLEEVE INSEAM LENGTH

Tha distance from tha enterior scye-point lendmark to the medial side of tha wrist landmark. Subject stands with arm slightly abducted and palm forward.



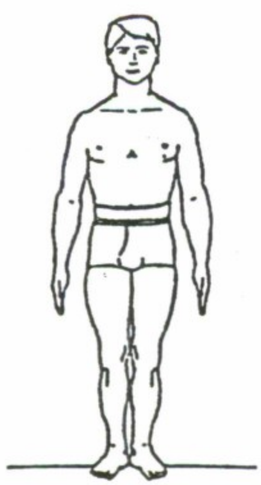
NECK CIRCUMFERENCE

The maximum circumference of the neck at a point just inferior to the bulge of the thyroid cartilage. The subject stands erect, head in the Frankfort plane.



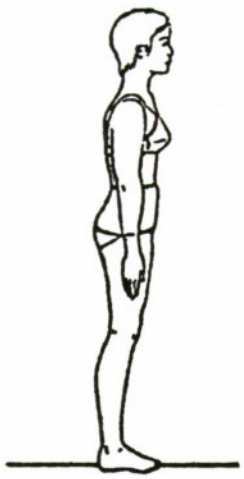
CHEST CIRCUMFERENCE

The horizontal circumference of the chest at the level of the nipples. The subject stands erect, looking straight ahead, heels together, and weight distributed equally on both feet.



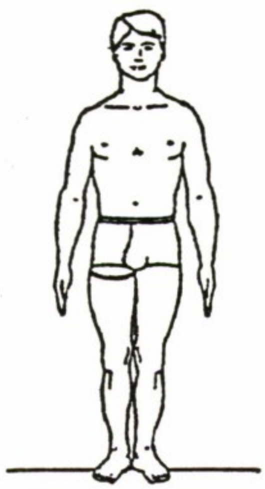
WAIST CIRCUMFERENCE

The horizontal circumference of the trunk at the level of the waist (omphalion) landmark. Subject stands erect, looking straight ahead, heels together and weight distributed equally on both feet.



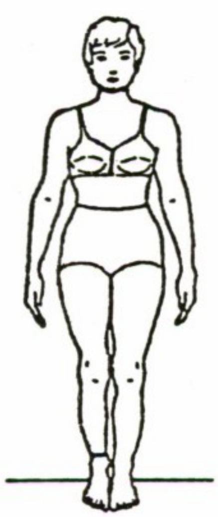
HIP (BUTTOCK) CIRCUMFERENCE

The circumference of the hips at the level of the meximum posterior protrusion of the buttocks. The subject stands erect, looking straight ahead, heels together, and weight distributed equally on both feet.



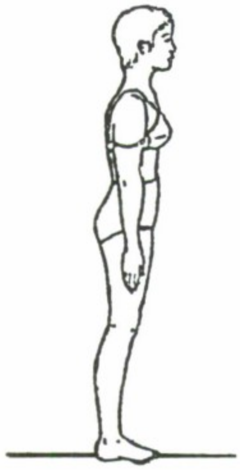
UPPER THIGH CIRCUMFERENCE

The circumference of the thigh at the level of the gluteel furrow. The subject stands erect, heels approximately 10 cm. apart, and weight distributed equally on both feet.



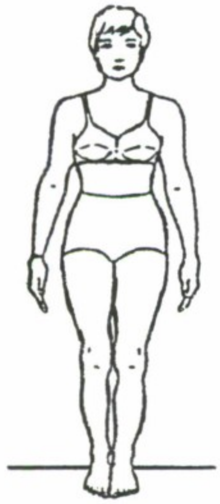
ANKLE CIRCUMFERENCE

The minimum circumference of the enkle in a plene perpendiculer to the long exis of the lower leg. The subject stends erect, heels approximately 10 cm. apert, and weight distributed equally on both feet.



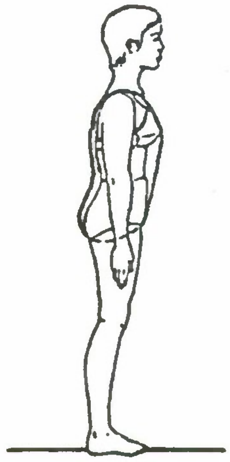
BICEPS CIRCUMFERENCE (RELAXED)

The circumference of the arm at the level of the biceps lendmerk. The subject stands with his arm slightly abducted.



WRIST CIRCUMFERENCE

The minimum circumference of the wrist et the level just proximel to the stylion lendmerk. The subject stends with the erm slightly ebducted.



VERTICAL TRUNK CIRCUMFERENCE

The circumference of the trunk measured by passing e tape between the legs, over the protrusion of the right buttock, and up the back to lie over the midshoulder landmerk. The other end of the tape is brought up over the right nipple to the midshoulder landmark. The subject stands with the legs slightly apart. The measurement is mede et the everege point of quiet respiretion.

APPENDIX B

MOBILITY AND REACH MEASUREMENT PROCEDURES

Prior to taking any measurements, adjust the measuring device for the individual subject in accordance with figure B-1. Take all measurements except Nos. 5A and B, Ankle Extension and Flexion. Prior to taking these measurements, readjust the measuring device in accordance with figure B-2. The following procedures will be followed for measuring the individual body motions.

1. FORWARD REACH AND TORSO DECLINATION (FIGURE B-3)

   a. Normal — Body back against seat back with arm extended forward.

   b. Extended — Lean body forward with arm extended to a "comfortable" reach position.

   c. Extended (strained) — Lean body forward to absolute maximum extended reach.

NOTE: For each position record both the linear reach distance from seat back and the angle of the torso in relation to the horizontal plane through the hip joint.

2. KNEE EXTENSION (FIGURE B-3)

   a. Normal — Upper leg flat on seat; lower leg at 90° angle to floor and seat.

   b. Extended — Raise lower leg to a comfortable position.

   c. Extended (strained) — Raise lower leg to maximum position.

   Record angles from vertical plane perpendicular to the floor through the knee joint.

3. SHOULDER FLEXION (FIGURE B-4)

   a. Relaxed Movement — Keeping arm straight raise arm above head to a comfortable raised position.

   b. Strained Movement — Continue raising arm to maximum flexed position.

   Record angle from horizontal plane through shoulder joint.

4. ELBOW FLEXION (FIGURE B-5)

   a. Relaxed Movement — With arm extended forward and plam of hand up, bend elbow raising lower arm to a comfortable position.

   b. Strained Movement — Continue raising lower arm to maximum flexed position.

   Record angles from horizontal plane through shoulder and elbow joints.

5. ANKLE (FIGURE B-5)

a. Extension — With lower leg at a 35° angle from perpendicular, measure angle of foot in relation to a line through the ankle joint and perpendicular to the lower leg when toe is lowered and the ankle joint is extended to its maximum.

b. Flexion — With lower leg at a 35° angle from perpendicular, measure angle of foot in relation to a line through the ankle joint and perpendicular to the lower leg when toe is brought up toward the lower leg flexing the ankle joint to its maximum.

6. NECK FLEXION (FIGURE B-6)

a. Dorsal — Head bent backward to maximum with torso perpendicular to seat.

b. Ventral — Head bent forward to maximum with torso perpendicular to seat.

Record angles from vertical plane through neck center and top of head.

7. HIP FLEXION (FIGURE B-6)

a. Raise upper leg to maximum with lower leg kept perpendicular to the floor. Record angle from horizontal plane through hip joint and parallel to the floor.

8. SHOULDER EXTENSION (FIGURE B-7)

a. From position with arm straight down perpendicular to floor, swing arm from shoulder joint toward back of seat. Record angle of arm from vertical plane through shoulder joint.

9. TORSO TORSION (FIGURE B-8)

a. Rotate torso to side with hips held restrained to seat and seat back. Record angle from vertical plane through mid-line of body.

10. NECK ROTATION (FIGURE B-8)

a. Relaxed Movement — Keeping shoulders against seat back, rotate head to side to a comfortable position.

b. Strained Movement — Continue rotating head to maximum turned position.

Record angle from midline of body through center of neck and nose.

11. SHOULDER (FIGURE B-9)

a. Abduction — With arm extended forward, parallel to the floor, swing arm to side as far back as possible keeping elbow joint extended.

b. Adduction — Swing arm toward midline of body as far as possible across chest.

Measure angle from plane perpendicular to seat back through the shoulder joint.

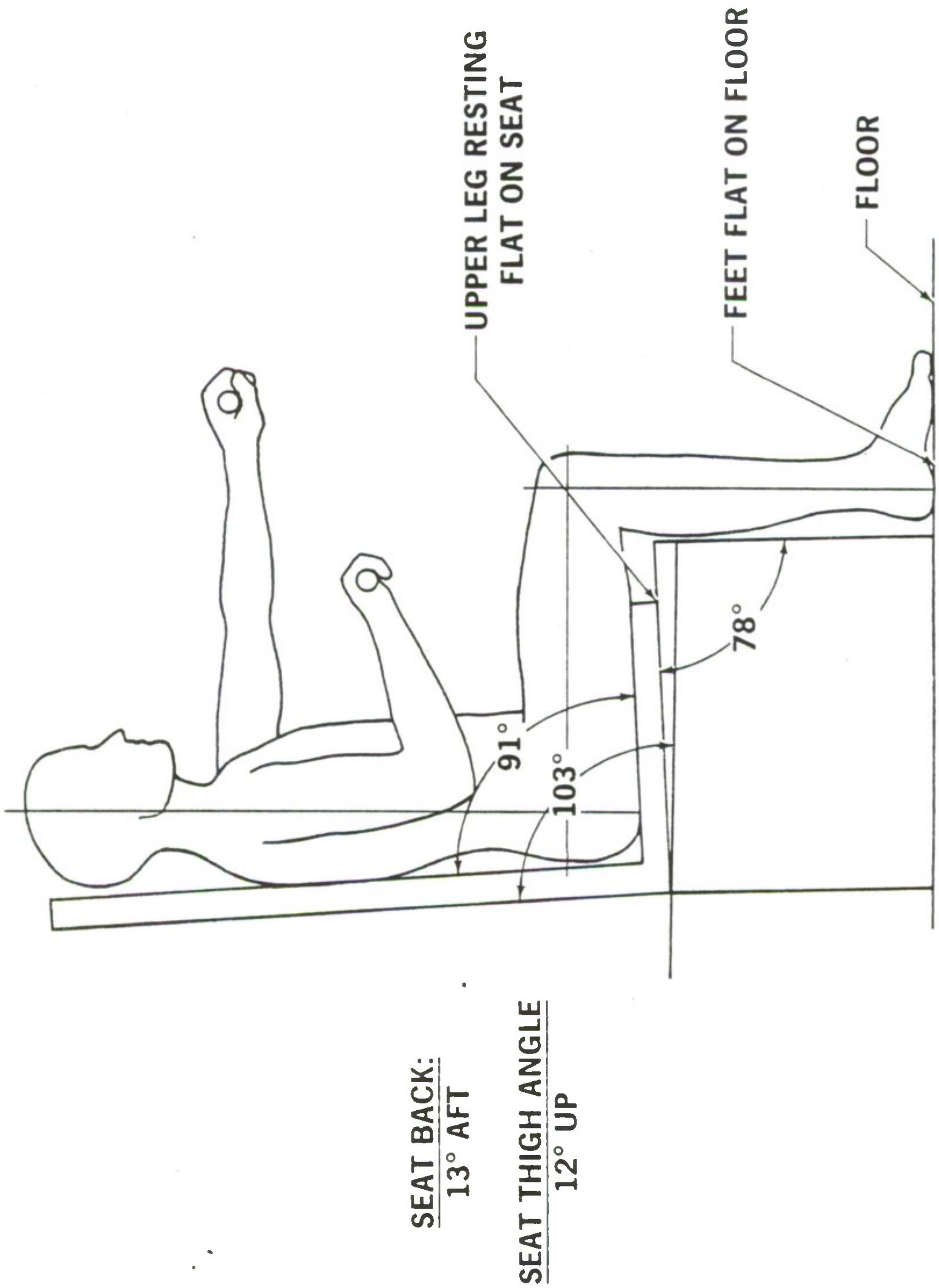


Figure B-1. Seat Attitude and Location for Measurement

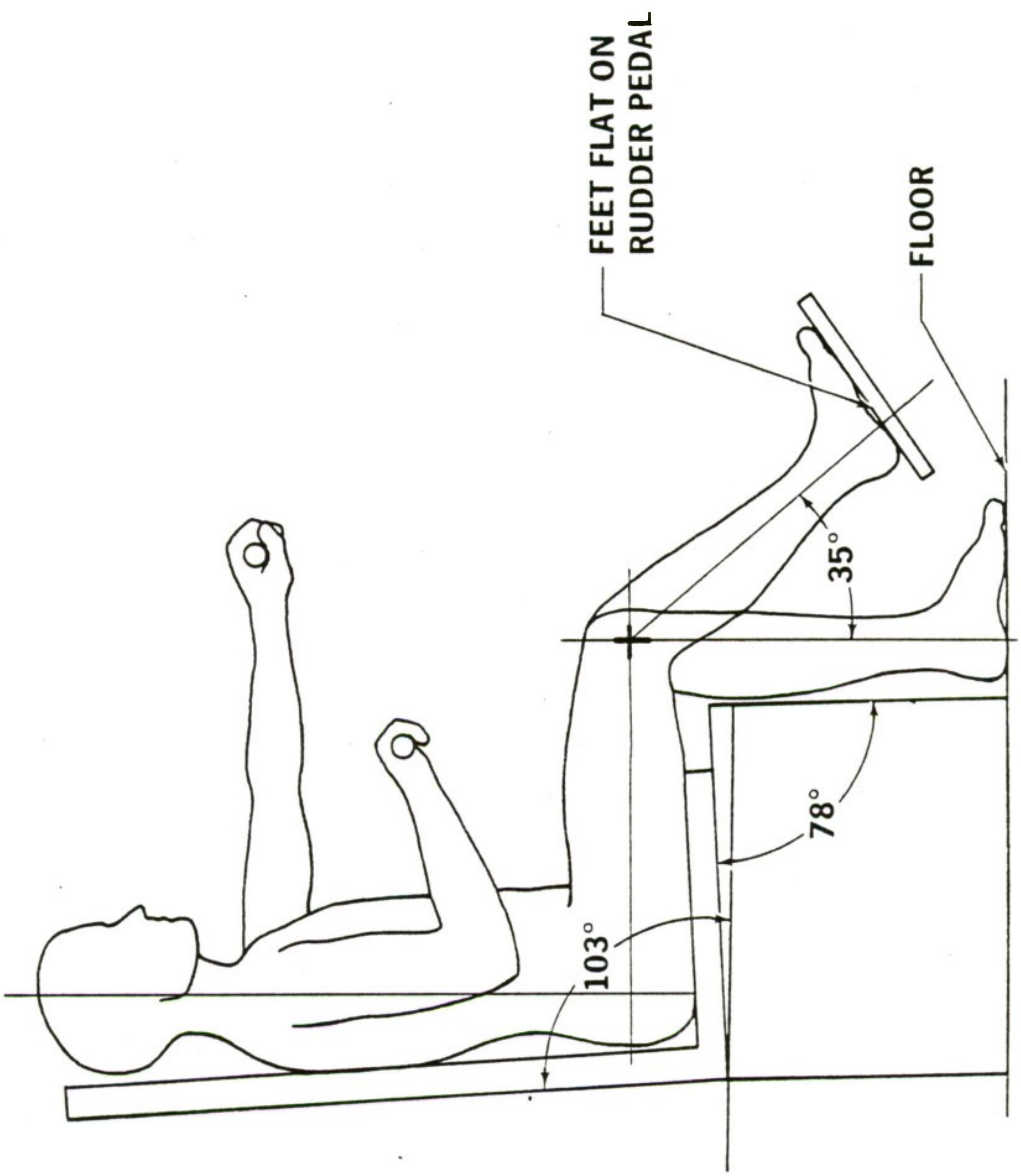


Figure B-2. Seat Attitude and Location for Measurement of Ankle Extension/Flexion (Measurement #5)

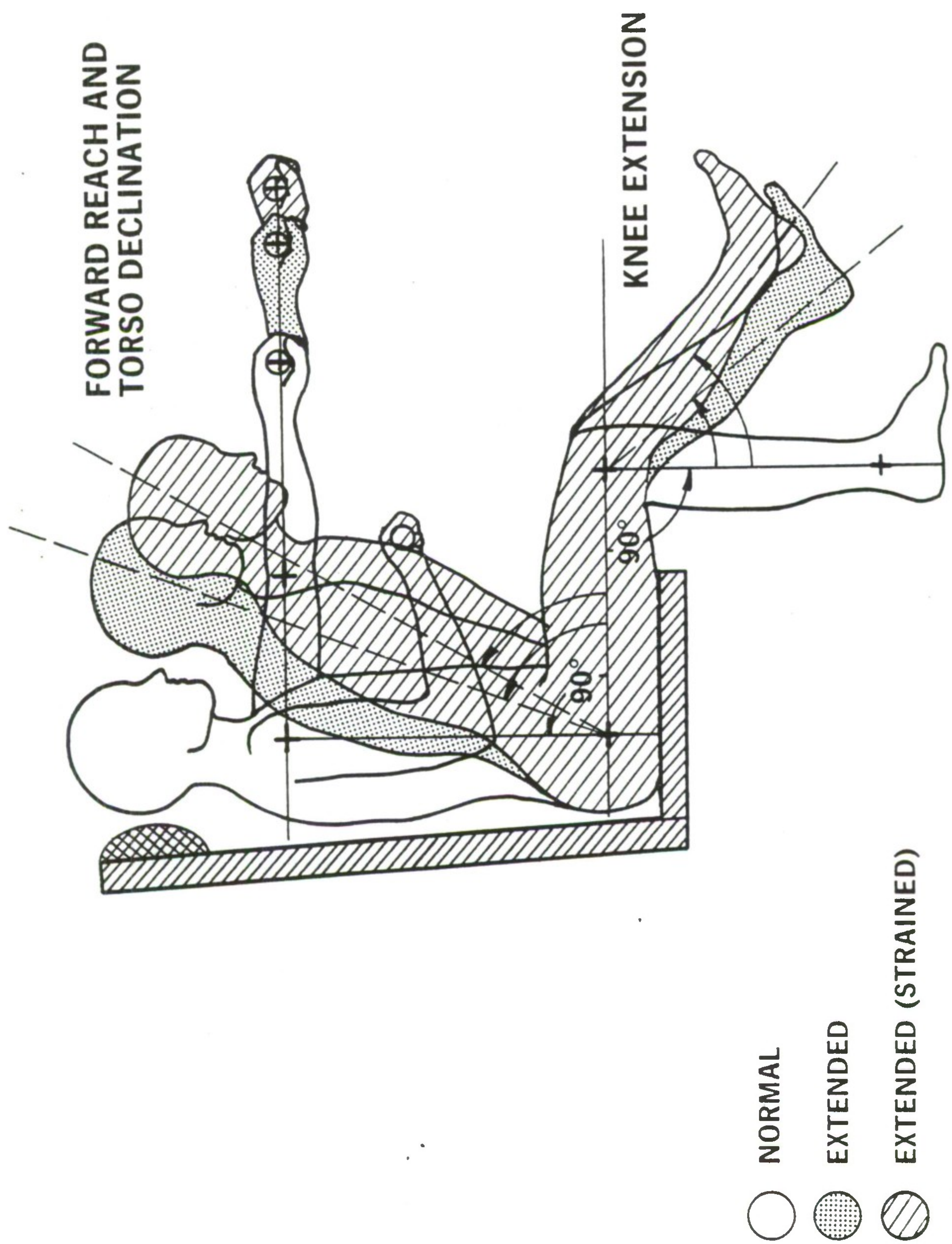

FORWARD REACH AND
TORSO DECLINATION
KNEE EXTENSION
90°
90°
90°
NORMAL
EXTENDED
EXTENDED (STRAINED)

Figure B-3

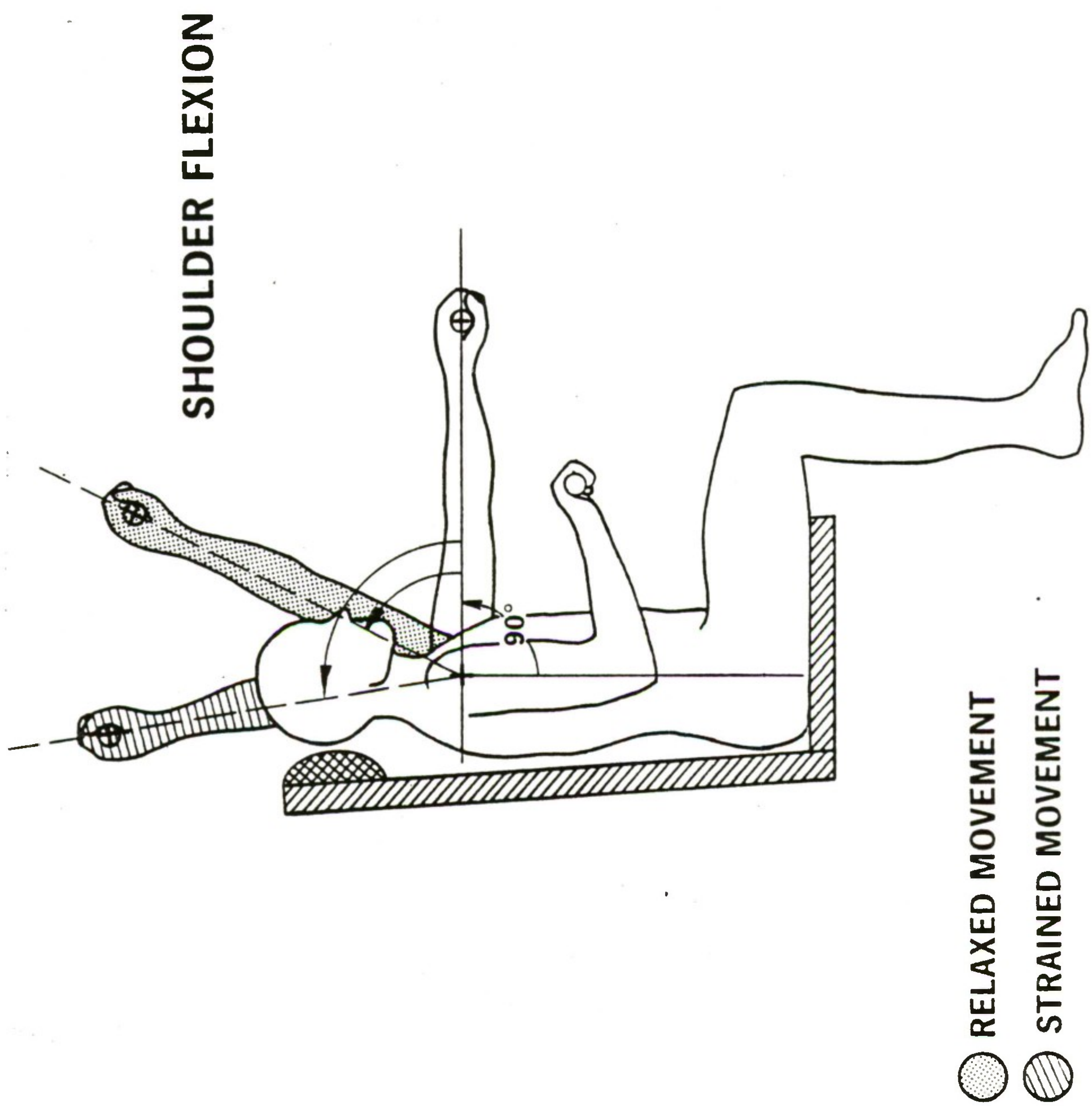


Figure B-4

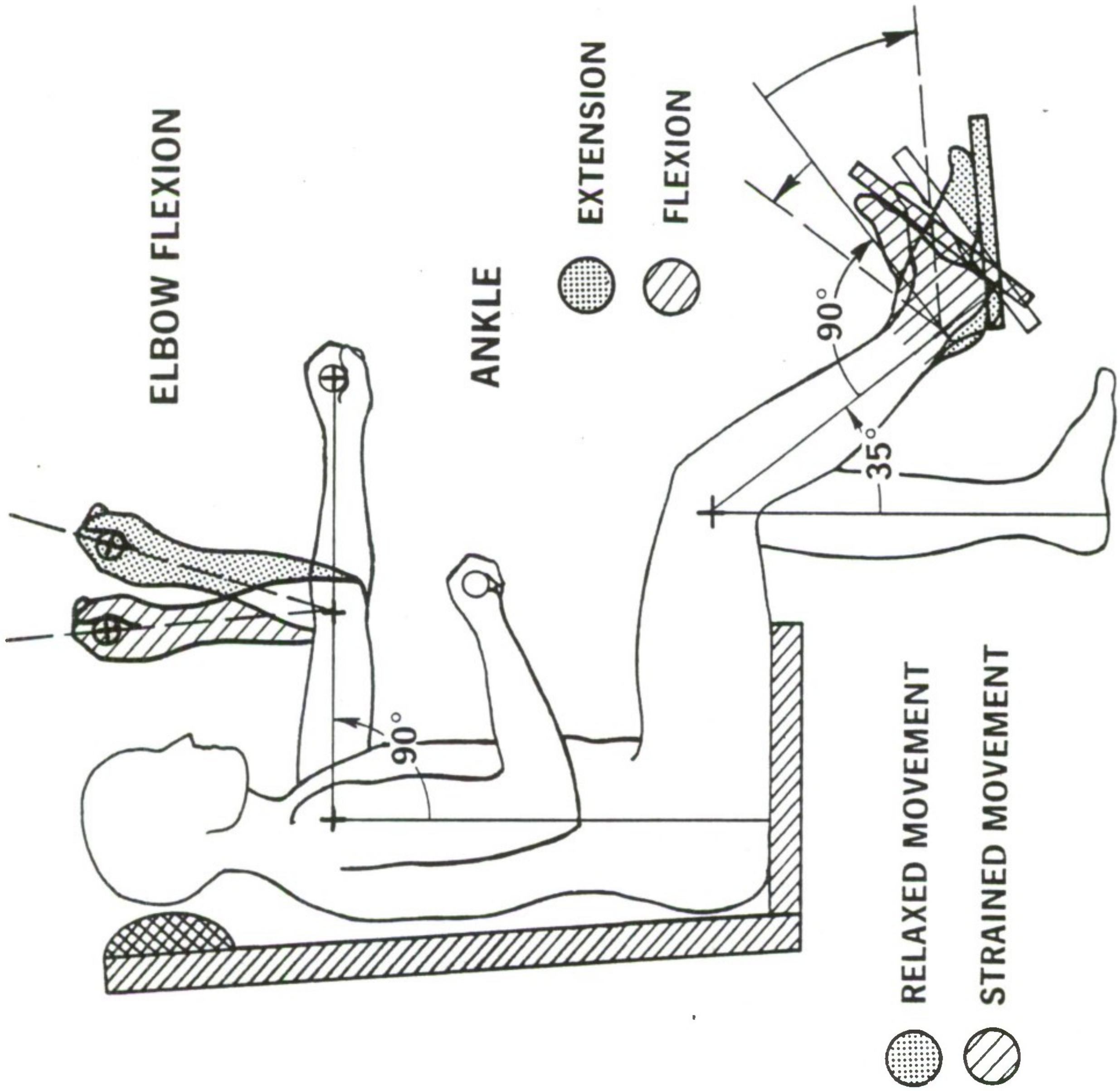

ELBOW FLEXION
ANKLE
EXTENSION
FLEXION
90°
90°
35°
RELAXED MOVEMENT
STRAINED MOVEMENT

Figure B-5

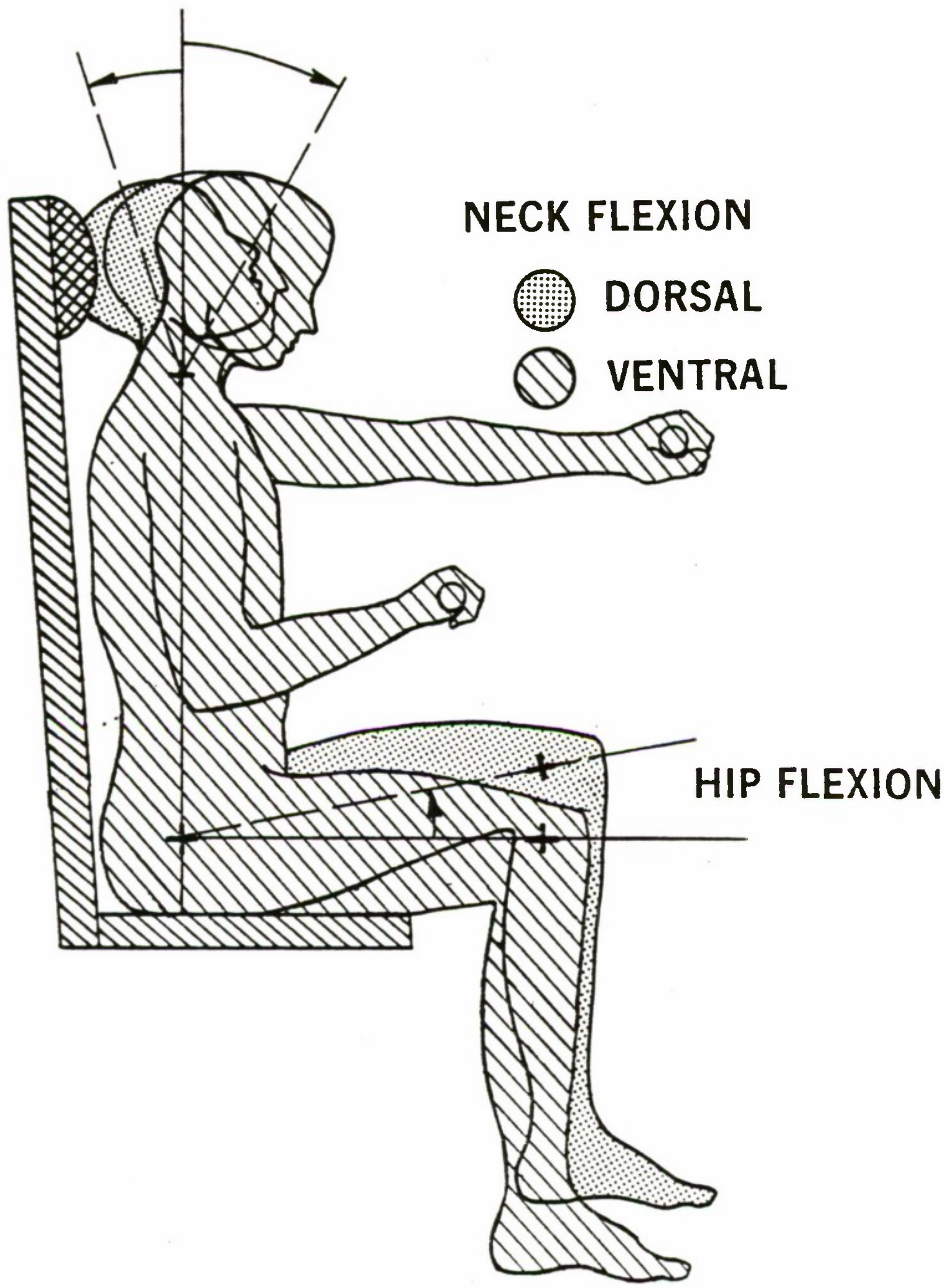


Figure B-6

SHOULDER EXTENSION

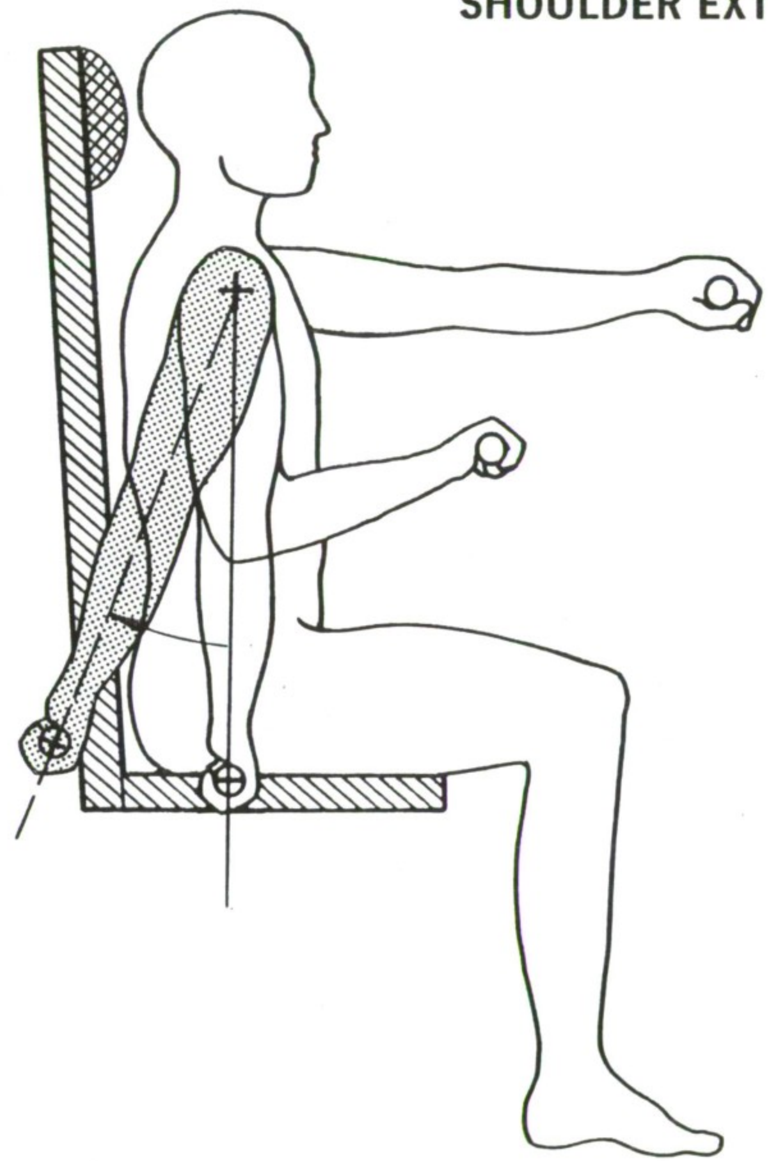
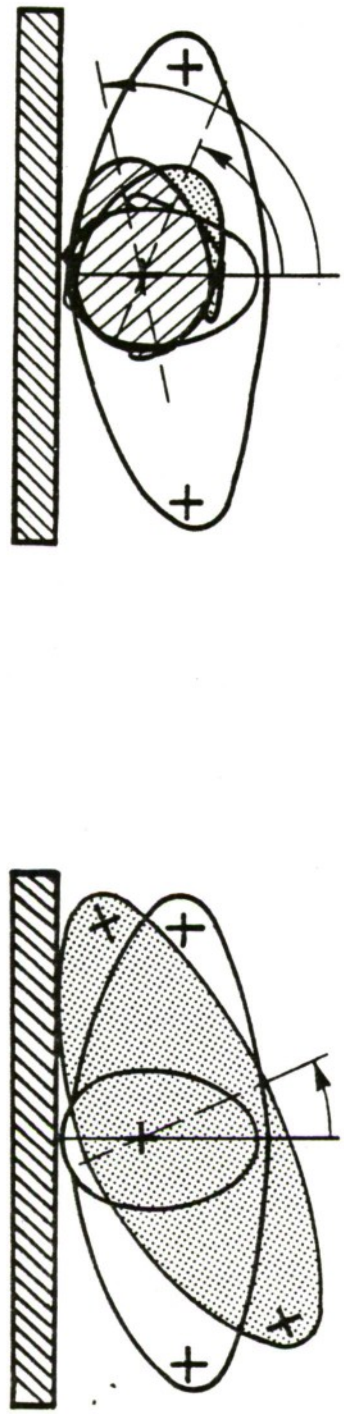


Figure B-7



NECK ROTATION

TORSO TORSION

Figure B-8

SHOULDER

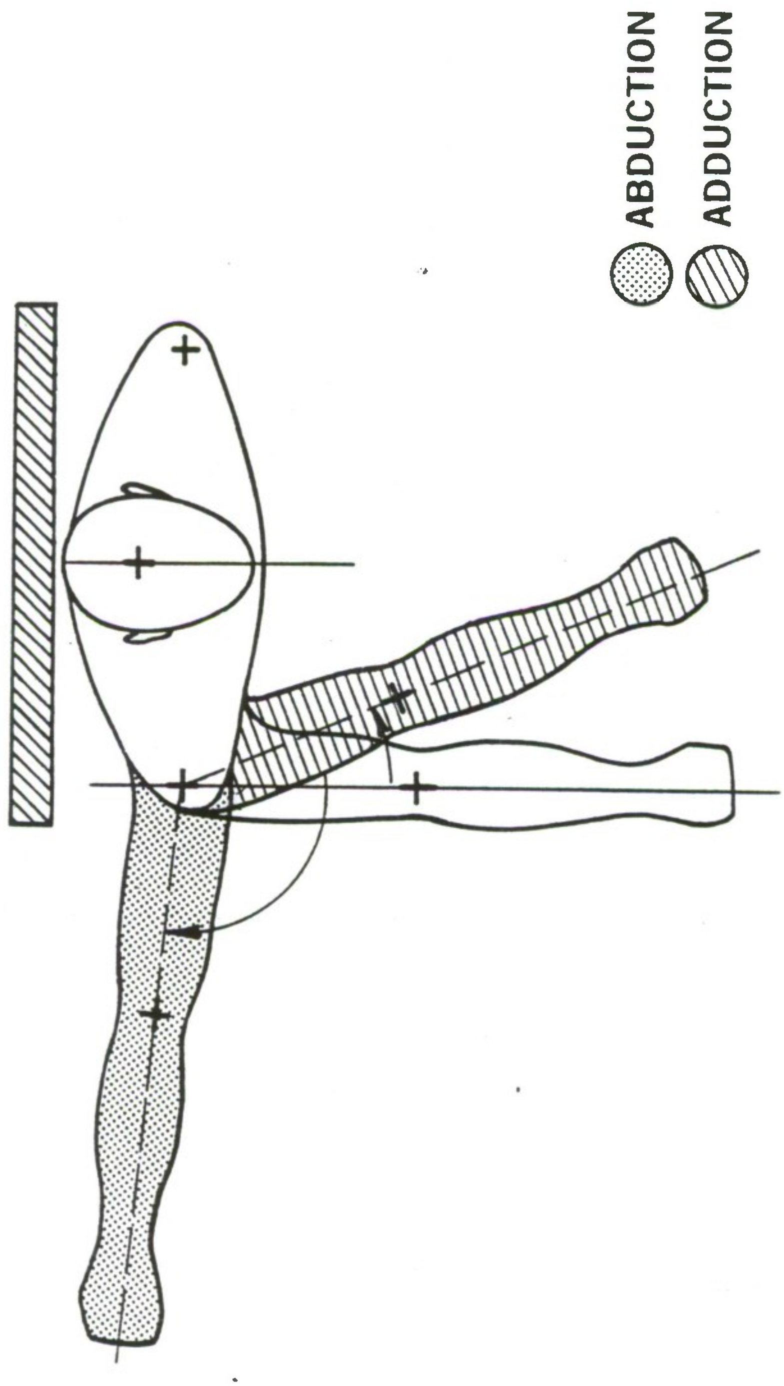


Figure B-9

APPENDIX C

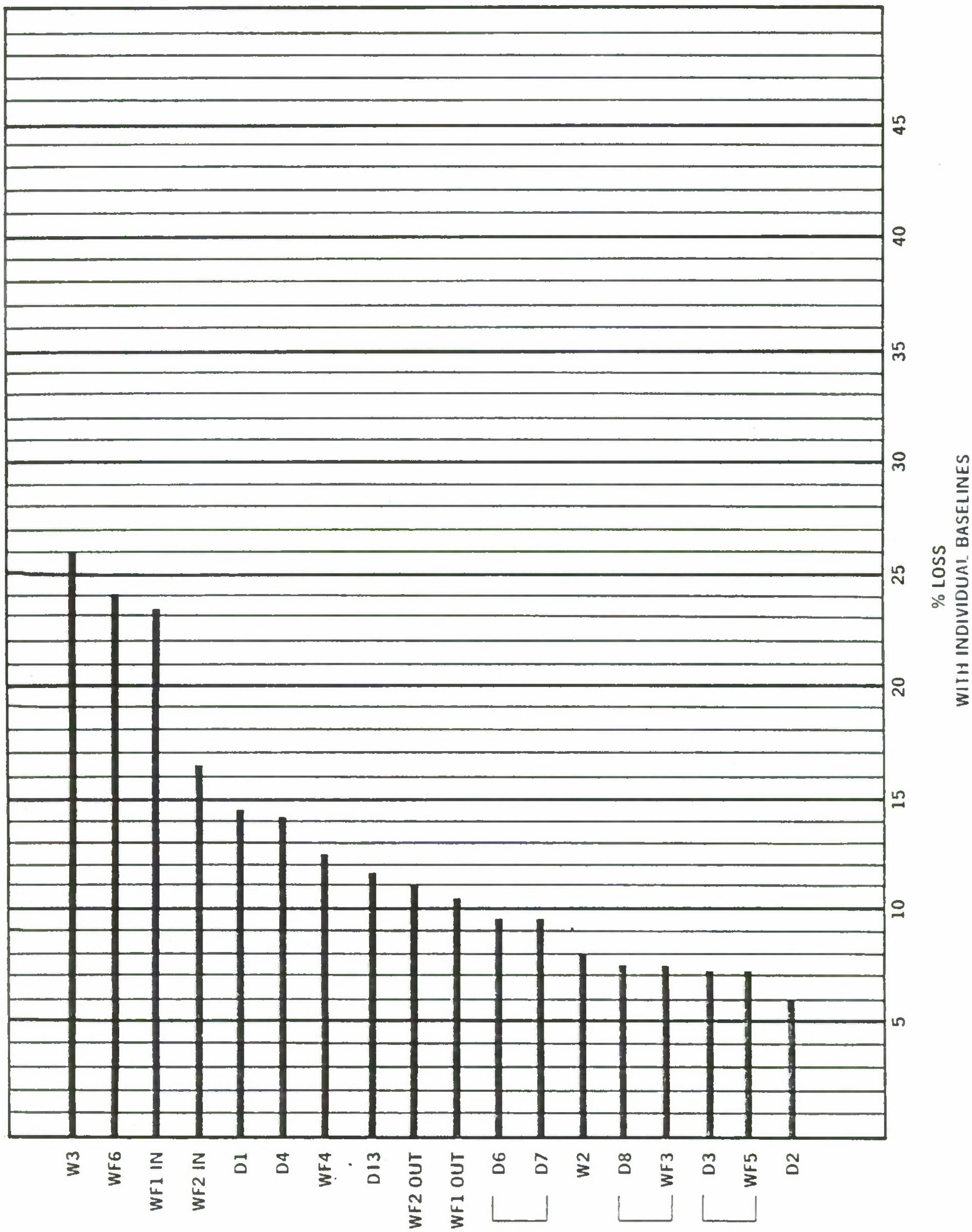
MOBILITY REDUCTION DATA

MOBILITY — % LOSSES FROM BASELINE (W1)

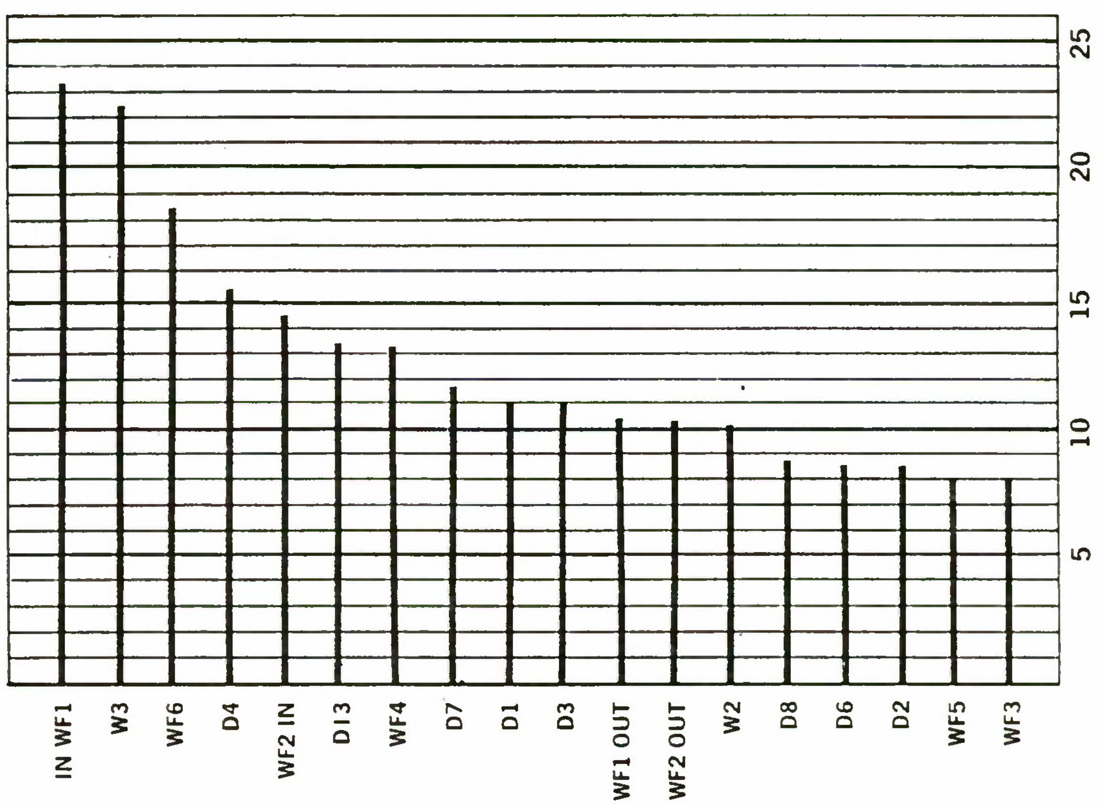
	FORWARD REACH	KNEE EXTENSION	ELBOW FLEXION	TORSO TORSION	NECK ROTATION	SHOULDER FLEXION	SHOULDER EXTENSION	SHOULDER ABDUCTION	SHOULDER ADDUCTION		GENERAL SHOULDER MOBILITY	GENERAL BODY MOBILITY	GEN. BODY MOD. W/O TORSO TORSION		NO. OF. S_s MEASURED
WF1 IN	12.5	2.8	9.1	64.8	27.9	29.5	28.9	6.1	28.4		23.2	23.3	18.2		8
WF1 OUT	3.7	NC	9.3	29.4	10.5	31.6	NC	4.9	5.3		10.5	10.5	8.2		5
WF2 IN	3.3	NC	10.7	50.2	1.3	24.7	18.9	1.6	21.6		16.7	14.7	10.3		4
WF2 OUT	2.2	6.4	1.7	37.2	2.0	23.0	9.1	1.6	10.0		10.9	10.4	7.0		4
WF3	6.8	NC	1.0	31.8	3.8	18.0	NC	NC	11.1		7.3	8.1	5.1		9
WF4	3.7	.6	6.1	47.7	10.6	15.9	NC	9.5	24.9		12.6	13.2	8.9		8
WF5	1.9	NC	NC	38.8	3.7	5.5	NC	NC	23.4		7.2	8.1	4.3		8
WF6	12.9	7.4	7.9	43.0	NC	34.8	13.3	4.1	43.5		23.9	18.5	15.5		6
W2	8.0	2.4	.9	30.4	10.1	11.7	12.7	4.1	3.9		8.1	9.4	6.7		10
W3	14.5	1.8	5.8	49.1	26.8	36.8	20.0	7.7	39.1		25.9	22.4	19.1		7
DI3	13.5	6.1	2.7	38.3	8.6	32.3	8.7	2.9	2.8		11.7	12.9	10.1		5
D1	9.2	2.9	9.5	16.7	4.0	23.4	NC	NC	34.0		14.4	11.1	10.4		6
D2	15.2	NC	2.8	25.4	8.9	22.4	NC	1.5	NC		6.0	8.5	6.4		4
D3	6.6	1.4	5.2	46.5	11.3	NC	1.2	NC	27.5		7.2	11.1	6.7		4
D4	7.9	3.7	7.3	44.9	17.4	19.2	25.1	NC	11.9		14.1	15.3	11.6		6
D6	6.5	3.1	6.1	14.7	10.3	10.7	9.6	7.1	10.0		9.4	8.7	7.9		4
D7	10.5	NC	4.6	41.8	11.9	13.2	13.0	NC	11.5		9.4	11.8	8.1		6
D8	11.2	NC	2.1	26.3	10.7	11.5	5.2	NC	12.4		7.3	8.8	6.6		6

NC — NO CHANGE

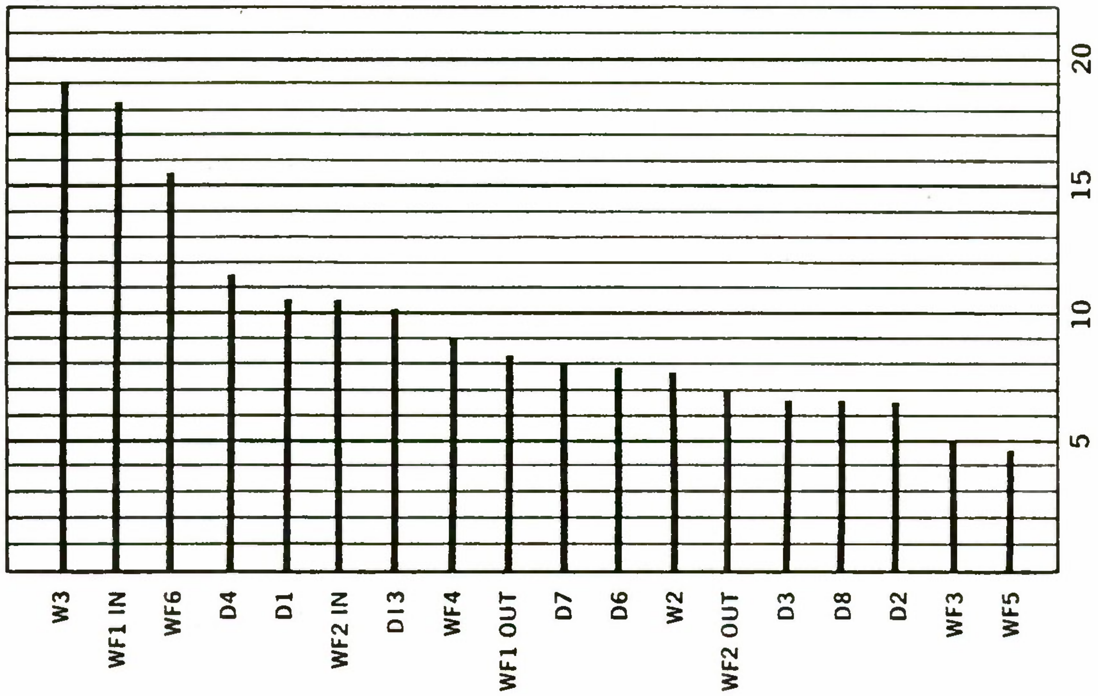
GENERAL SHOULDER MOBILITY LOSS



GENERAL BODY MOBILITY LOSS

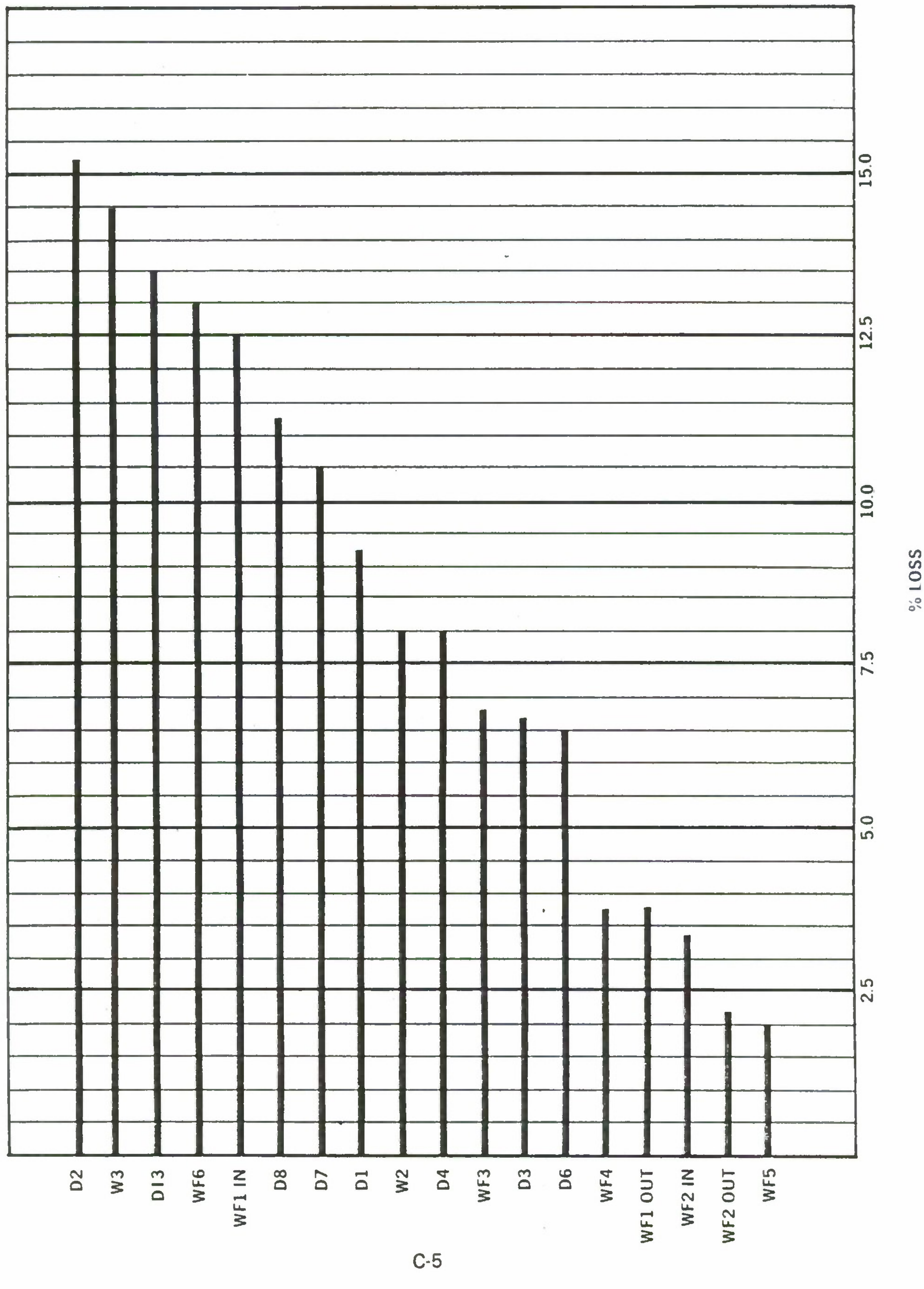


WITH INDIVIDUAL BASELINES

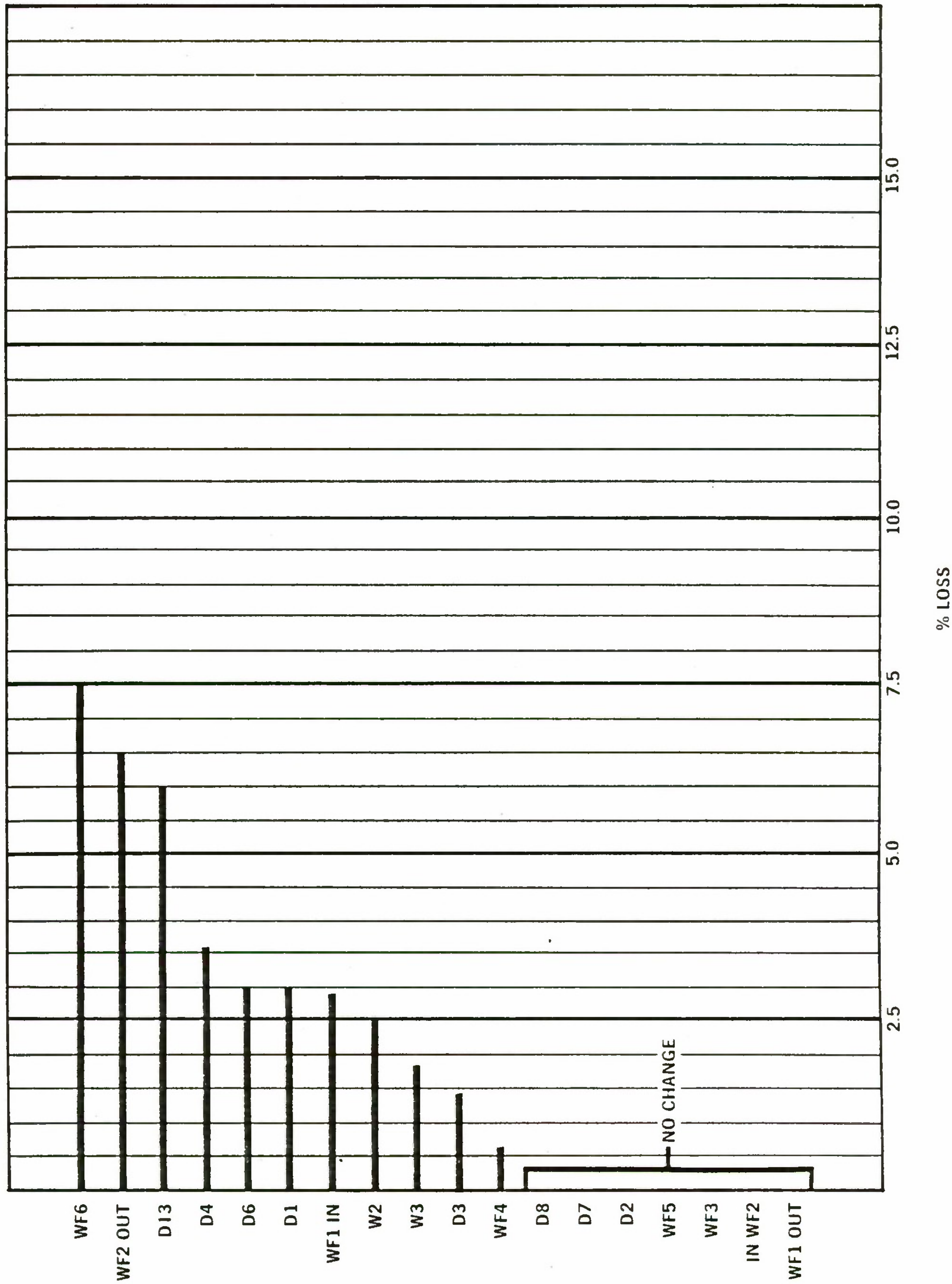


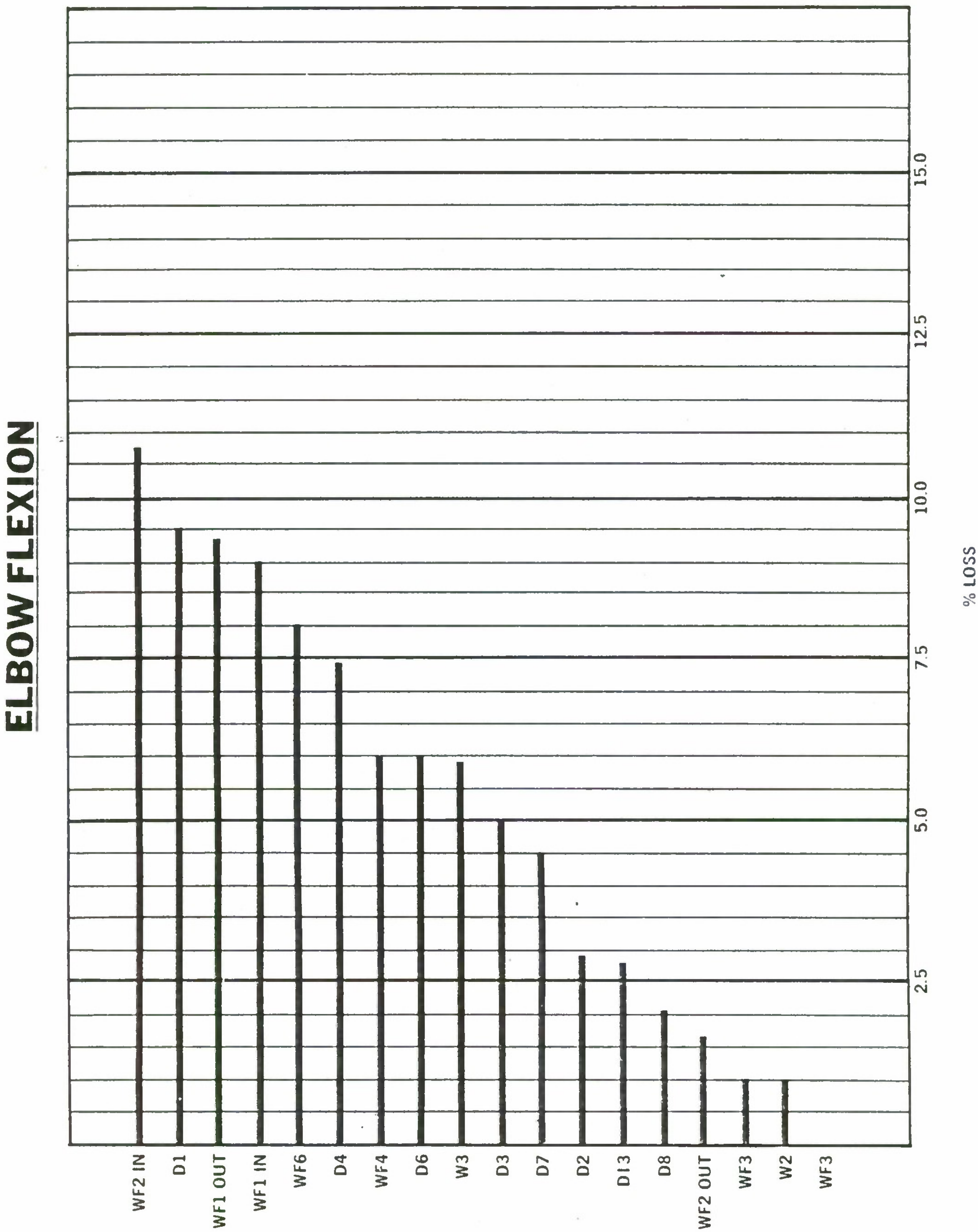
WITHOUT TORSO TORSION AND
WITH INDIVIDUAL BASELINES

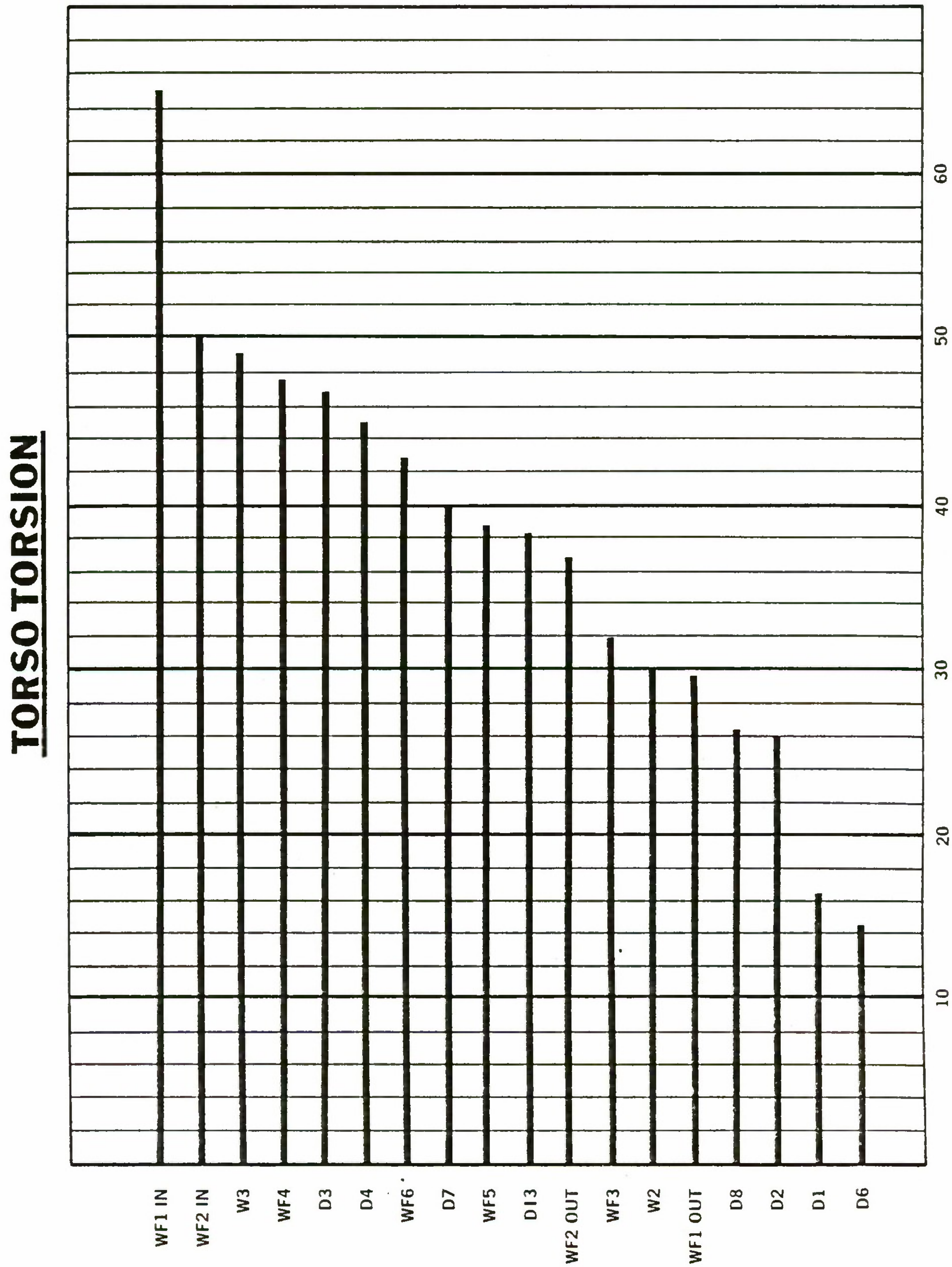
FORWARD REACH

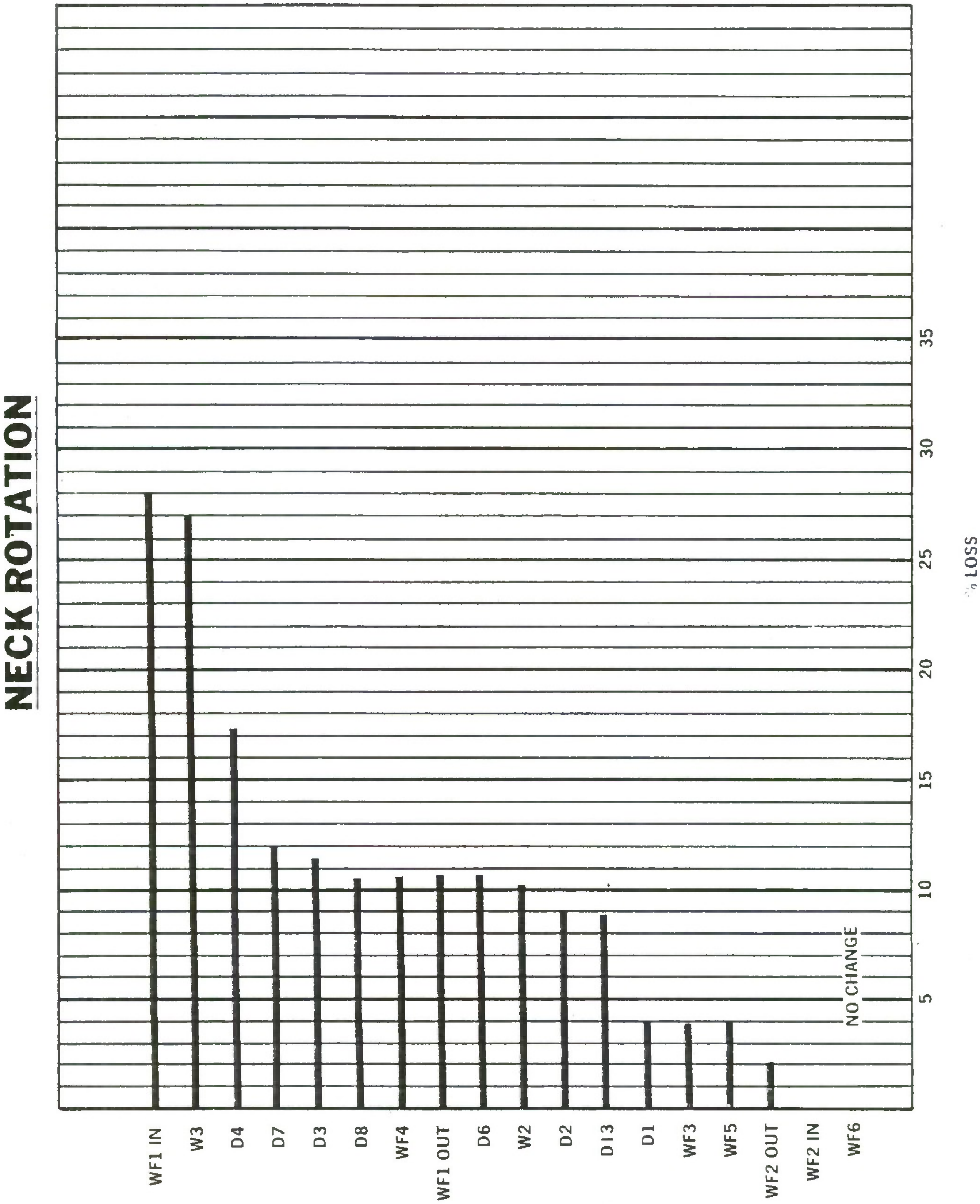


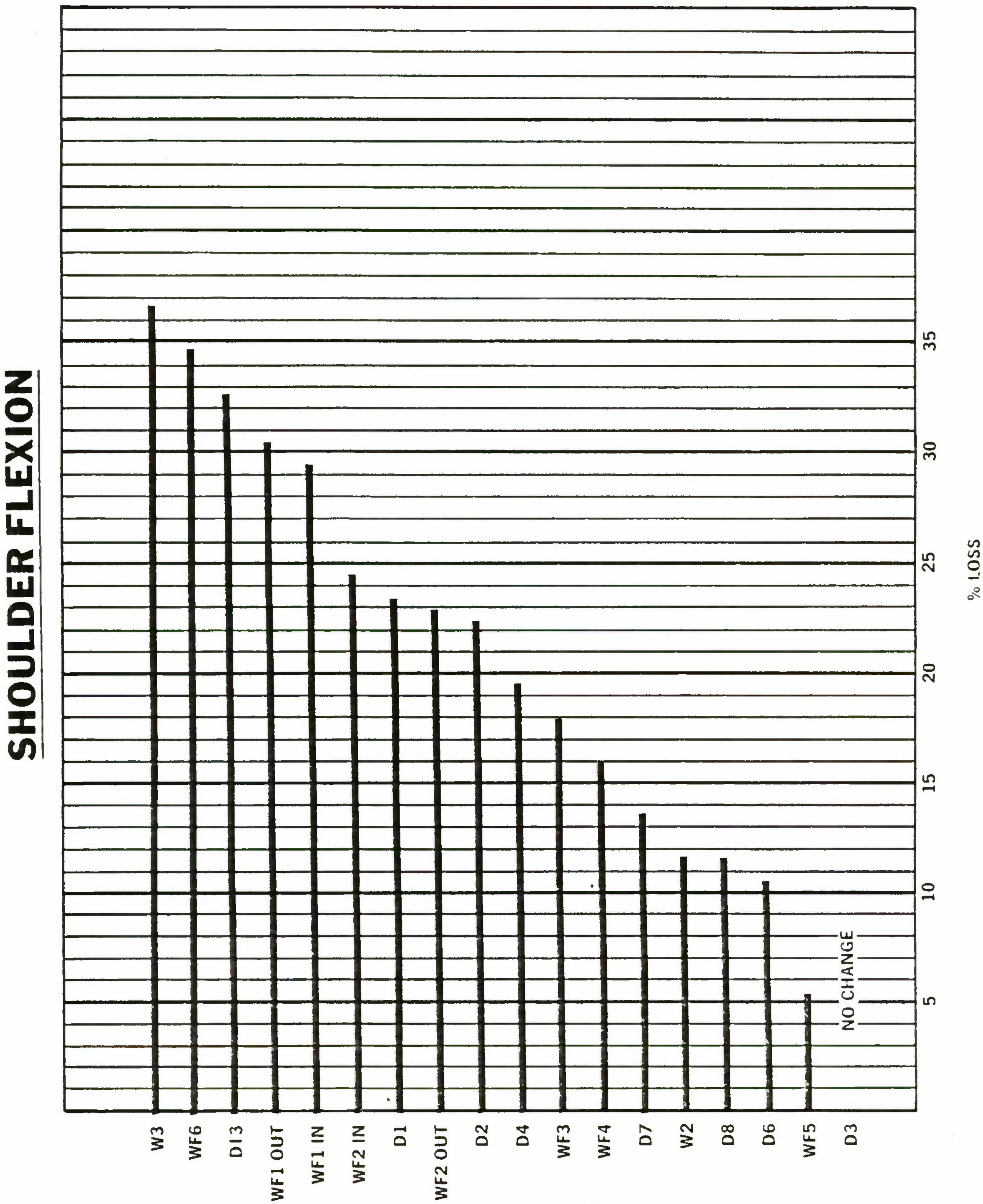
KNEE EXTENSION



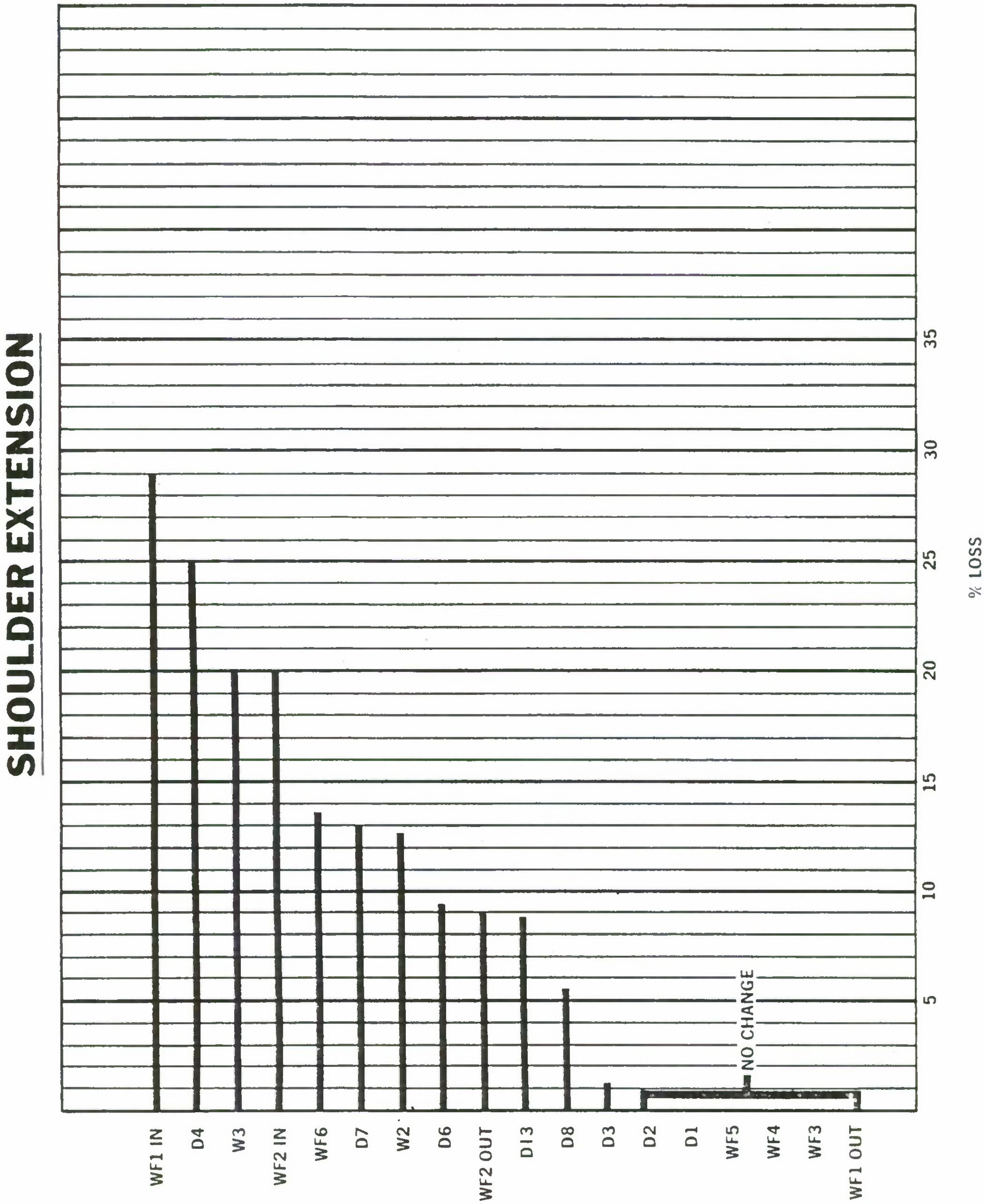

ELBOW FLEXION
% LOSS
2.5
5.0
7.5
10.0
12.5
15.0
WF2 IN
D1
WF1 OUT
WF1 IN
WF6
D4
WF4
D6
W3
D3
D7
D2
D13
D8
WF2 OUT
WF3
W2
WF3

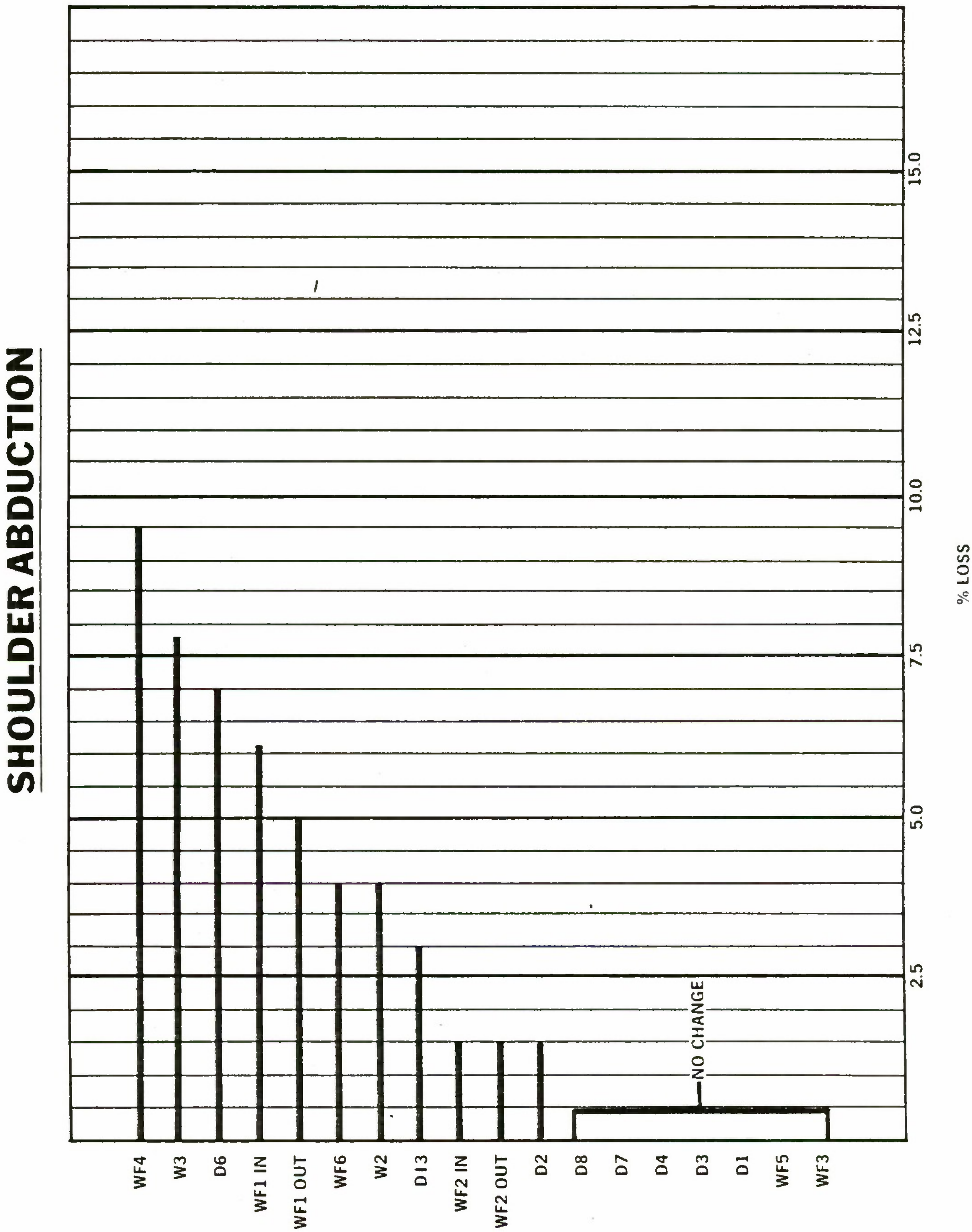

TORSO TORSION
% LOSS
10
20
30
40
50
60
WF1 IN
WF2 IN
W3
WF4
D3
D4
WF6
D7
WF5
D13
WF2 OUT
WF3
W2
WF1 OUT
D8
D2
D1
D6

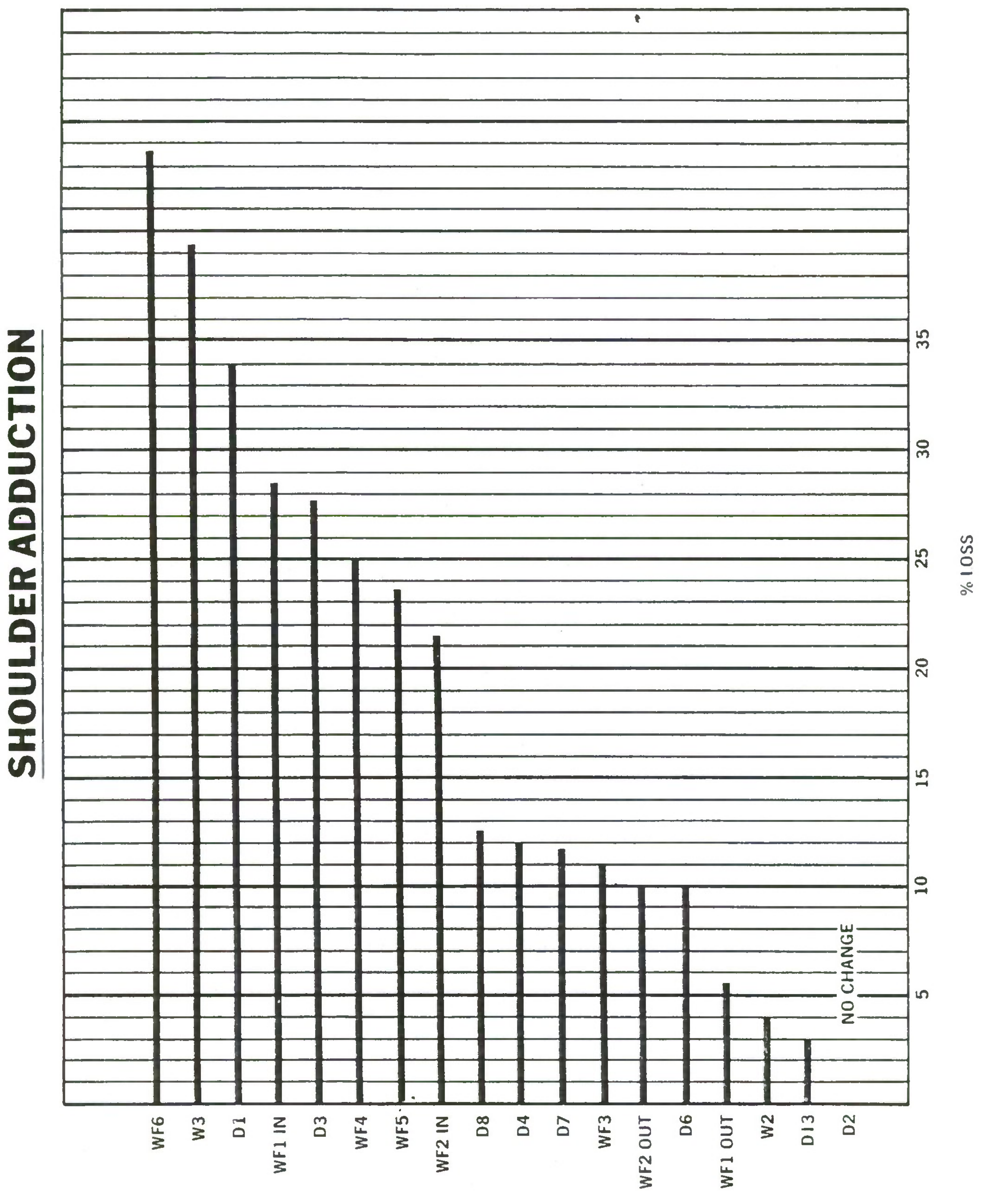

NECK ROTATION
% LOSS
5
10
15
20
25
30
35
NO CHANGE
WF1 IN
W3
D4
D7
D3
D8
WF4
WF1 OUT
D6
W2
D2
D13
D1
WF3
WF5
WF2 OUT
WF2 IN
WF6



SHOULDER FLEXION
% LOSS
5
10
15
20
25
30
35
NO CHANGE
W3
WF6
D13
WF1 OUT
WF1 IN
WF2 IN
D1
WF2 OUT
D2
D4
WF3
WF4
D7
W2
D8
D6
WF5
D3


SHOULDER EXTENSION
% LOSS
5
10
15
20
25
30
35
NO CHANGE
WF1 IN
D4
W3
WF2 IN
WF6
D7
W2
D6
WF2 OUT
D13
D8
D3
D2
D1
WF5
WF4
WF3
WF1 OUT


SHOULDER ABDUCTION
% LOSS
2.5
5.0
7.5
10.0
12.5
15.0
NO CHANGE
WF4
W3
D6
WF1 IN
WF1 OUT
WF6
W2
D13
WF2 IN
WF2 OUT
D2
D8
D7
D4
D3
D1
WF5
WF3


SHOULDER ADDUCTION
% LOSS
5
10
15
20
25
30
35
NO CHANGE
WF6
W3
D1
WF1 IN
D3
WF4
WF5
WF2 IN
D8
D4
D7
WF3
WF2 OUT
D6
WF1 OUT
W2
D13
D2

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